Illinois Drainage Guide

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Contents

Preface

Drainage is one of the most important and profitable practices of conservation farming. Through drainage, Illinois farmers can improve crop production on millions of acres of fertile cropland. Moreover, because drainage permits level land to be farmed more intensively, rolling land, which is more subject to erosion, can be farmed less intensively.

The two main components of a drainage system are the outlet and the conveyance system. Outlet ditches usually cannot be crossed with farm machinery, and they must be continually maintained. The conveyance system brings water from the field to the outlet by means of either a surface or subsurface drainage system.

Surface drainage removes surplus water from the surface of crop fields by means of shallow ditches that can readily be crossed with farm equipment. This type of drainage is adapted to farms where the land is flat and the subsoil is heavy and compact. Surface drainage may be used alone or supplemented with subsurface drainage.

The marked advantage of subsurface drains over surface ditches is that drains can be placed where needed without cutting the land into relatively small, irregularly shaped fields. Subsurface drains remove wet spots, so that the whole field can be planted and cultivated and the crop harvested when conditions are right for operations over most of the field. Properly installed subsurface drains require little maintenance.

Designing an effective drainage system is a complex task, however. Each aspect of a surface or subsurface drainage system is dependent upon several variables. For example, the size of a drain in a subsurface system is dependent upon, among other things, a drainage coefficient, the size of the area to be drained, the grade of the drain, and the internal roughness of the drain.

Furthermore, a decision about one aspect of a drainage system may narrow the choices available for other aspects. For example, an early decision about the grade necessary to drain the area may determine the choices of drain size. In designing a drainage system, therefore, one must work back and forth between several aspects to meet all the conditions of a particular drainage problem.

This circular is an introduction to the many variables in both surface and subsurface drainage systems. It provides detailed descriptions of the components of each system, using figures and tables to familiarize the reader with the concepts involved, and it gives fairly thorough explanations about the relationships among the various components of each system.

The circular should be especially useful to drainage system planners and land improvement contractors who construct and install drainage systems. For one, it serves as a handy reference to the general philosophy of drainage design. More importantly, it provides general guidelines for designing systems that are specific for Illinois soil types. These soil-specific guidelines are the result of numerous studies and field data and can point the direction of the initial design stages. In addition, this circular provides several tables and figures that can be used quickly and easily to make some important initial decisions about various components of a drainage system. Finally, the circular provides recommended methods of construction and installation.

This publication also should be useful to the landowner or farm operator who wishes to better understand the intricacies of drainage system design and installation. The text is written in descriptive, primarily nontechnical language and should not pose any problem to a reader who is only beginning to think about investing in a drainage system.

Please note that the recommendations in this circular were developed on a statewide basis. As a result, modifications may be necessary for application to local conditions.

This publication also is not intended to be used by itself to actually design a drainage system. Many charts, tables, and other aids that are essential in making final decisions have been collected and published elsewhere, and it is not the intention of this publication to duplicate these efforts. Where other materials are needed for actual design purposes, the reader is referred to the appropriate publications. In general, the landowner, farm operator, or contractor will most likely need the help of a professional technician to design a system, even if all other materials are consulted. But with the information provided in this circular, these readers will be able to ask pertinent questions and to better understand the concepts that the technician will use to solve the individual drainage problem.

Questions concerning the recommendations in this guide should be directed to the Department of Agricultural Engineering, University of Illinois at Urbana-Champaign, 1304 W. Pennsylvania Avenue, Urbana, IL 61801, or to the State Conservation Engineer, Soil Conservation Service, United States Department of Agriculture, Springer Federal Building, 301 N. Randolph Street, Champaign, IL 61820.

Drainage Guidelines

Drainage recommendations

Illinois has a wide variety of soils, and each differs in some way from all the others. The guidelines on pages 4 to 8 will help you determine what drainage practices are best suited to your particular soil. These guidelines are based upon field tests and upon past experience with drainage practices on various soils.

The soils listed in the guidelines are grouped according to the soil characteristics that are most relevant to the design of manmade drainage systems. The two primary characteristics are the rate at which water will move through the soil (referred to as soil permeability or hydraulic conductivity and measured in inches per hour) and the degree of wetness before any drainage practices have been applied (referred to as natural drainage). Two other important characteristics, which help determine subgroups in the guidelines, are soil depth and topographic position. Some soils are shallow to bedrock, shale, or sand. Others occur on bottomlands and have stream flooding problems. And some are located in saucerlike depressions where they have no natural surface outlet. Other factors, such as land use, affect drainage design but are not dealt with in the guidelines.

In the guidelines, the drainage groups are assigned a number (**1** to **4**) and a capital letter (**A** or **B**). The number indicates the degree of soil permeability:

- **1** Rapidly permeable (more than 6 inches per hour) and moderately rapidly permeable (2 to 6 inches per hour)
- **2** Moderately permeable (0.6 to 2 inches per hour)
- **3** Moderately slowly permeable (0.2 to 0.6 inch per hour)
- **4** Slowly permeable (0.06 to 0.2 inch per hour) and very slowly permeable (less than 0.06 inch per hour)

The capital letter indicates the natural drainage of that group of soils. Natural drainage is a good indicator of the relative yield increase you can expect from most crops if you install an adequate drainage system. The yield increase will probably be greater for the soils with the poorest natural drainage. The natural drainage classes are:

- **A** Poorly drained (the water table is at or near the surface during the wetter seasons of the year) and very poorly drained (the water table remains near, at, or above the surface much of the time).
- **B** Somewhat poorly drained (the water table is near the surface only during the very wettest periods).

Landowners and operators, farm managers, drainage contractors, and others can determine the soil type and number from county soil survey reports, the conservation plan of the farm, or unpublished soil maps that are available at the local soil and water conservation district office. To find the drainage group of the soil, refer to the alphabetical list of soils on page 2 or the numerical list on page 3.

Some small areas of wet soils cannot be shown on maps on the scale commonly used for soil surveys. A few very minor soils that need drainage and that are shown on soil maps are omitted from the alphabetical and numerical lists. Assistance with problems on these soils and with planning and laying out drainage systems is available from the Soil Conservation Service through the local soil and water conservation district office. Information and publications on soils can be obtained from county Extension offices and the Department of Agronomy, University of Illinois at Urbana-Champaign.

Construction near utilities

Illinois has centers of high population that are serviced by many miles of public and private utilities such as telephone, telegraph, and electric transmission lines, pipelines, railroad tracks, and highways. In designing and constructing a drainage system, it is extremely important that you know the location of any utility (especially pipelines) near the drainage project. Many utilities are well marked, but some are not.

If a buried utility line or a highway is to be added to an area, landowners should obtain information about the engineering design work. This information is needed to assure them that the installation will not interfere significantly with present and future drainage work. Information can be obtained from the utility company or highway authority.

Whenever possible, avoid building drain lines across buried cables, pipelines, and other facilities. You can keep the number of crossings to a minimum by installing special lines (called interceptor lines) parallel to the facilities. Find out from the owner of the pipeline or cable its exact location and depth. Perhaps the owner can also inform you of any special construction requirements and supervise work in the vicinity of the line. You may have to obtain a special permit and meet certain other requirements to install drain lines across a county, state, or federal highway.

In working around a buried pipeline, the landowner and contractor are naturally subject to some safety hazards. They may also be liable for the cost of interrupted service and repair if they damage the buried utility and have not properly notified the owner of their plans to work near it.

Alphabetical List of Soils and Their Drainage Group Number

Soil Series	Soil No.	Drainage group
Adrian muck	777	1A
Aholt	670	4A
Ambraw	302	2A
Andres	293	2B
Aptakisic	365	2B
Ashkum	232	3A
Atterberry	61	2B
Aurelius	319	1A
Banlic	787	4B
Beardstown	188	2B
Beaucoup	70	2A
Beecher	298	4B
Belknap	382	2B
Binghampton	355	2B
Birds	334	3A
Blackoar	603	2A
Blount	23	4B
Bluford	13	4B
Bonfield	493	2B
Bonnie	108	3A
Booker	457	4A
Bowdre	589	3B
Brenton	149	2B
Brooklyn	136	4A
Bryce	235	4A
Cairo	590	4A
Calamine	746	3A
Calco	400	2A
Canisteo	347	2A
Cape	422	4A
Chauncey	287	4A
Cisne	2	4A
Clarence	147	4B
Clarksdale	257	3B
Clyde	648	2A
Coffeen	428	2B
Colo	402	2A
Coulterville	621	4B
Comfrey	776	2A
Cowden	112	4A
Creal	337	3B
Darmstadt	620	4B
Darroch	740	2B
Darwin	71	4A
Del Rey	192	4B
Denny	45	4A
Denrock	262	4B
Drummer	152	2A
Dupo	180	2B
Ebbert	48	4A
Edgington	272	3A
Edinburg	249	3A
Elburn	198	2B
Elliott	146	3B
Faxon	516	2A
Fieldon	380	2A
Fincastle	496	2B
Flanagan	154	2B
Frankfort	320	4B
Fults	591	4A
Gilford	201	1A
Ginat	460	4A
Gorham	162	3B
Granby	513	1A
Harco	484	2B
Harpster	67	2A
Hartsburg	244	2A
Harvel	252	2A
Hayfield	771	2B
Herbert	62	2B
Herrick	46	3B
Homer	326	2B
Hoopeston	172	2B
Houghton muck	103	1A
Houghton peat	97	1A
Hoyleton	3	4B
Huey	120	4A
Hurst	338	4B
Ipava	43	2B
Iva	454	2B
Jacob	85	4A
Joliet	314	2A
Joy	275	2B
Kane	343	2B
Karnak	426	4A
Kendall	242	2B
Keomah	17	3B
Kernan	554	3B
Knight	191	3A
La Hogue	102	2B
Lawler	647	2B
Lawndale	683	2B
Lawson	451	2B
Lena muck	210	1A
Lisbon	59	2B
Littleton	81	2B
Loran	572	3B
Lukin	167	4B
Marine	517	4B
Marissa	176	3B
Marshan	772	2A
Martinton	189	3B
Matherton	342	2B
Maumee	89	1A
McFain	248	4A
McGary	173	4B
Milford	69	3A
Millbrook	219	2B
Millington	82	2A
Millsdale	317	3A
Mokena	295	3B
Monee	229	4A
Montgomery	465	4A
Morocco	501	2B
Mundelein	442	2B
Muscatine	41	2B
Muskego muck	637	1A
Nachusa	649	2B
Nameoki	592	4B
Nappanee	228	4B
Newberry	218	4A
Niota	261	4A
Oconee	113	4B
Odell	490	2B
Okaw	84	4A
Orio	200	2A
Orion	415	2B
Otter	76	2A
Palms muck	100	1A
Papineau	42	2B
Parkville	619	3B
Patton	142	2A
Pella	153	2A
Peotone	330	3A
Petrolia	288	3A
Piasa	474	4A
Piopolis	420	4A
Racoon	109	4A
Radford	74	2B
Rantoul	238	4A
Raub	481	2B
Reddick	594	2A
Reesville	723	2B
Ridgeville	151	2B
Ridott	743	3B
Riley	452	2B
Robbs	335	4B
Roby	184	2B
Romeo	316	2A
Rowe	230	4A
Ruark	178	3A
Rushville	16	4A
Rutland	375	3B
Sabina	236	2B
Sable	68	2A
Sawmill	107	2A
Selma	125	2A
Selma, bedrock substratum	508	2A
Sexton	208	4A
Shadeland	555	3B
Shiloh	138	3A
Shoals	424	2B
Shullsburg	745	3B
Starks	132	2B
Stoy	164	4B
Streator	435	3A
Stronghurst	278	2B
Sunbury	234	2B
Swygert	91	4B
Thorp	206	4A
Tice	284	2B
Titus	404	4A
Toronto	353	2B
Traer	633	4A
Troxel	197	2B
Virden	50	3A
Virgil	104	2B
Wabash	83	4A
Wagner	26	4A
Wakeland	333	2B
Wallkill	292	2A
Washtenaw	296	2A
Watseka	49	2B
Wauconda	697	2B
Weinbach	461	4B
Weir	165	4A
Wesley	141	2B
Westland	300	2A
Whitson	116	3A
Will	329	2A
Wynoose	12	4A
Zipp	524	4A
Zwingle	576	4A

Numerical List of Soils and Their Drainage Group Number

Soil No.	Soil Series	Drainage group
2	Cisne	4A
3	Hoyleton	4B
12	Wynoose	4A
13	Bluford	4B
16	Rushville	4A
17	Keomah	3B
23	Blount	4B
26	Wagner	4A
41	Muscatine	2B
42	Papineau	2B
43	Ipava	2B
45	Denny	4A
46	Herrick	3B
48	Ebbert	4A
49	Watseka	2B
50	Virden	3A
59	Lisbon	2B
61	Atterberry	2B
62	Herbert	2B
67	Harpster	2A
68	Sable	2A
69	Milford	3A
70	Beaucoup	2A
71	Darwin	4A
74	Radford	2B
76	Otter	2A
81	Littleton	2B
82	Millington	2A
83	Wabash	4A
84	Okaw	4A
85	Jacob	4A
89	Maumee	1A
91	Swygert	4B
97	Houghton peat	1A
100	Palms muck	1A
102	La Hogue	2B
103	Houghton muck	1A
104	Virgil	2B
107	Sawmill	2A
108	Bonnie	3A
109	Racoon	4A
112	Cowden	4A
113	Oconee	4B
116	Whitson	3A
120	Huey	4A
125	Selma	2A
132	Starks	2B
136	Brooklyn	4A
138	Shiloh	3A
141	Wesley	2B
142	Patton	2A
146	Elliott	3B
147	Clarence	4B
149	Brenton	2B
151	Ridgeville	2B
152	Drummer	2A
153	Pella	2A
154	Flanagan	2B
162	Gorham	3B
164	Stoy	4B
165	Weir	4A
167	Lukin	4B
172	Hoopeston	2B
173	McGary	4B
176	Marissa	3B
178	Ruark	3A
180	Dupo	2B
184	Roby	2B
188	Beardstown	2B
189	Martinton	3B
191	Knight	3A
192	Del Rey	4B
197	Troxel	2B
198	Elburn	2B
200	Orio	2A
201	Gilford	1A
206	Thorp	4A
208	Sexton	4A
210	Lena muck	1A
218	Newberry	4A
219	Millbrook	2B
228	Nappanee	4B
229	Monee	4A
230	Rowe	4A
232	Ashkum	3A
234	Sunbury	2B
235	Bryce	4A
236	Sabina	2B
238	Rantoul	4A
242	Kendall	2B
244	Hartsburg	2A
248	McFain	4A
249	Edinburg	3A
252	Harvel	2A
257	Clarksdale	3B
261	Niota	4A
262	Denrock	4B
272	Edgington	3A
275	Joy	2B
278	Stronghurst	2B
284	Tice	2B
287	Chauncey	4A
288	Petrolia	3A
292	Wallkill	2A
293	Andres	2B
295	Mokena	3B
296	Washtenaw	2A
298	Beecher	4B
300	Westland	2A
302	Ambraw	2A
314	Joliet	2A
316	Romeo	2A
317	Millsdale	3A
319	Aurelius	1A
320	Frankfort	4B
326	Homer	2B
329	Will	2A
330	Peotone	3A
333	Wakeland	2B
334	Birds	3A
335	Robbs	4B
337	Creal	3B
338	Hurst	4B
342	Matherton	2B
343	Kane	2B
347	Canisteo	2A
353	Toronto	2B
355	Binghampton	2B
365	Aptakisic	2B
375	Rutland	3B
380	Fieldon	2A
382	Belknap	2B
400	Calco	2A
402	Colo	2A
404	Titus	4A
415	Orion	2B
420	Piopolis	4A
422	Cape	4A
424	Shoals	2B
426	Karnak	4A
428	Coffeen	2B
435	Streator	3A
442	Mundelein	2B
451	Lawson	2B
452	Riley	2B
454	Iva	2B
457	Booker	4A
460	Ginat	4A
461	Weinbach	4B
465	Montgomery	4A
474	Piasa	4A
481	Raub	2B
484	Harco	2B
490	Odell	2B
493	Bonfield	2B
496	Fincastle	2B
501	Morocco	2B
508	Selma, bedrock substratum	2A
513	Granby	1A
516	Faxon	2A
517	Marine	4B
524	Zipp	4A
554	Kernan	3B
555	Shadeland	3B
572	Loran	3B
576	Zwingle	4A
589	Bowdre	3B
590	Cairo	4A
591	Fults	4A
592	Nameoki	4B
594	Reddick	2A
603	Blackoar	2A
619	Parkville	3B
620	Darmstadt	4B
621	Coulterville	4B
633	Traer	4A
637	Muskego muck	1A
647	Lawler	2B
648	Clyde	2A
649	Nachusa	2B
670	Aholt	4A
683	Lawndale	2B
697	Wauconda	2B
723	Reesville	2B
740	Darroch	2B
743	Ridott	3B
745	Shullsburg	3B
746	Calamine	3A
771	Hayfield	2B
772	Marshan	2A
776	Comfrey	2A
777	Adrian muck	1A
787	Banlic	4B

DRAINAGE GROUP 1A (rapidly or moderately rapidly permeable, poor or very poorly drained)

Soil number and name: **97 Houghton peat**, **100 Palms muck**, **103 Houghton muck**, **210 Lena muck**, **319 Aurelius muck**, **637 Muskego muck**, **777 Adrian muck**

Subsurface drainage[a]*:* 3 to 5 feet deep, 80 to 120 feet apart.

Remarks: Difficult to keep subsurface drains on grade. If tiled, long sections of perforated pipe may be used. Drainage systems that permit control of water table level will prevent excessive subsidence (lowering of surface elevation) of muck and peat. Open ditches work satisfactorily and can be blocked to control water level. Muck underlain with mineral soil at 1 to 3½ feet requires on-site investigation to determine feasibility of drainage.

Soil number and name: **89 Maumee**, **201 Gilford**, **513 Granby**

Subsurface drainage[a]*:* 3 to 4 feet deep, 100 to 150 feet apart.

Shallow surface drainage[b]*:* Space 330 to 660 feet apart.

Remarks: Sandy soils may be droughty in some seasons if uncontrolled drainage is used. Drains may plug with sand or lose alignment. Drainage systems that permit control of water table level are desirable if economically feasible. To prevent tile from clogging, butt tile close together and encase in one of the following ways:
(1) Place tile on mat of bituminous impregnated fiberglass, heavy plastic, or heavy asphaltic roll roofing with porous fiberglass sheet over top to encase tile completely.
(2) Encase tile with 6 inches of gravel, stone, or other inert material. Material should be well graded, no more than 5 percent finer than that passing through a No. 200 sieve and no coarser than that passing through a 1½-inch mesh screen.
To prevent clogging in tubing, encase tubing with prefabricated nonbiodegradable filter materials such as fiberglass, spun-bonded nylon fabric, and plastic filter cloth.

DRAINAGE GROUP 2A (moderately permeable, poor or very poorly drained)

Soil number and name: **67 Harpster**, **68 Sable**, **125 Selma**, **142 Patton**, **152 Drummer**, **153 Pella**, **244 Hartsburg**, **252 Harvel (Montgomery County)**, **594 Reddick**, **648 Clyde**

Subsurface drainage[a]*:* 3 feet deep, 80 to 100 feet apart, or 4 feet deep, 100 to 120 feet apart.

Shallow surface drainage: Random surface ditches from depressions may be needed to supplement subsurface drains.

Remarks: Surface inlets to subsurface drains will be beneficial in depressions if surface drainage is not practical.

Soil number and name: **200 Orio**, **300 Westland**, **329 Will**, **347 Canisteo**, **380 Fieldon**, **772 Marshan**

Subsurface drainage[a]*:* 3 feet deep, 100 to 120 feet apart.

Shallow surface drainage: May be used as an alternative to subsurface drainage.

Remarks: May have sand or gravel at 2 to 3½ feet. Keep subsurface drains above sand and gravel if possible, and use sealed joints in sand and gravel.

Soil number and name: **314 Joliet**, **316 Romeo**, **508 Selma, bedrock substratum**, **516 Faxon**

Subsurface drainage[a]*:* Space 80 to 100 feet apart where bedrock is greater than 3 feet deep.

Shallow surface drainage[b]*:* Space 330 to 660 feet apart.

Remarks: Bedrock may be near surface. On-site investigation required to determine depth.

Source: These guidelines are based upon data collected by the U.S. Soil Conservation Service, the American Society for Testing and Materials, the American Society of Agricultural Engineering, and the Departments of Agricultural Engineering and Agronomy, University of Illinois at Urbana-Champaign.

[a] The wider spacings listed here are for the greater drain depths. Place the drains as deep as the underlying material will permit.

[b] The spacing listed for surface ditches is based on the assumption that surface water will travel from one ditch to the next if there is no crown between ditches. If there is a natural crown or one has been formed by grading, the spacing would be from the crown to the ditch.

Soil number and name:	**70 Beaucoup**	**107 Sawmill**	**302 Ambraw**	**603 Blackoar**
	76 Otter	**292 Wallkill**	**400 Calco**	**776 Comfrey**
	82 Millington	**296 Washtenaw**	**402 Colo**	

Subsurface drainage[a]: 3 to 3½ feet deep, 80 to 100 feet apart.

Shallow surface drainage[b]: Surface ditches may be needed to supplement subsurface drains or in place of drains. Space 330 to 660 feet apart. With land grading, spacing may be increased. On-site assistance needed to determine maximum cut for land grading.

Remarks: Bottomland soils subject to overflow if not protected. Wallkill is underlain with muck in depressions. Outlets for subsurface drains not always available. Check for pockets of sand and muck or peat layers when planning a subsurface drainage system.

DRAINAGE GROUP 2B (moderately permeable, somewhat poorly drained)

Soil number and name:	**42 Papineau**	**172 Hoopeston**	**343 Kane**	**647 Lawler**
	49 Watseka	**184 Roby**	**355 Binghampton**	**683 Lawndale**
	141 Wesley	**326 Homer**	**493 Bonfield**	**771 Hayfield**
	151 Ridgeville	**342 Matherton**	**501 Morocco**	

Subsurface drainage: Helps to use perforated drains with filter material around them.

Shallow surface drainage: Use random ditches where depressions occur.

Remarks: Underlain with sand or gravel. Drainage usually not needed. (See remarks under Group 1A.) Papineau and Wesley have slowly permeable, clayey, underlying material beginning at depths of 20 to 40 inches. On-site investigation needed to determine depth. Watseka and Morocco have rapid permeability.

Soil number and name:	**41 Muscatine**	**149 Brenton**	**242 Kendall**	**481 Raub**
	43 Ipava	**154 Flanagan**	**275 Joy**	**484 Harco**
	59 Lisbon	**188 Beardstown**	**278 Stronghurst**	**490 Odell**
	61 Atterberry	**197 Troxel**	**293 Andres**	**496 Fincastle**
	62 Herbert	**198 Elburn**	**353 Toronto**	**649 Nachusa**
	81 Littleton	**219 Millbrook**	**365 Aptakisic**	**697 Wauconda**
	102 LaHogue	**234 Sunbury**	**442 Mundelein**	**723 Reesville**
	104 Virgil	**236 Sabina**	**454 Iva**	**740 Darroch**
	132 Starks			

Subsurface drainage[a]: 3 feet deep, 80 to 100 feet apart, or 4 feet deep, 100 to 120 feet apart.

Shallow surface drainage: Use random ditches where depressions occur.

Remarks: Drainage improvement will increase yield in some years. Increase will be smaller and less frequent, however, than on soils in Group 2A.

Soil number and name:	**74 Radford**	**333 Wakeland**	**424 Shoals**	**452 Riley**
	180 Dupo	**382 Belknap**	**428 Coffeen**	
	284 Tice	**415 Orion**	**451 Lawson**	

Subsurface drainage[a]: 3 feet deep, 80 to 100 feet apart, or 4 feet deep, 100 to 120 feet apart.

Shallow surface drainage: Surface ditches may be needed where there are depressions or areas that have no subsurface drain outlet.

Remarks: Bottomland soils subject to overflow unless protected. May have sandy lenses. Drainage may not be needed. Riley has sand below 2 feet. (See remarks under Group 1A for sandy soils.)

See footnotes on page 4.

DRAINAGE GROUP 3A (moderately slowly permeable, poorly or very poorly drained)

Soil number and name:				
	50 Virden	**138 Shiloh**	**232 Ashkum**	**330 Peotone**
	69 Milford	**178 Ruark**	**249 Edinburg**	**435 Streator**
	116 Whitson	**191 Knight**	**272 Edgington**	**746 Calamine**

Subsurface drainage[a]: 3 to 3½ feet deep, 75 to 95 feet apart.

Shallow surface drainage: Use random ditches where depressions occur. Land grading may also be helpful.

Remarks: In depression, surface inlets to subsurface drains are an alternative to surface ditches.

Soil number and name: **317 Millsdale**

Subsurface drainage[a]: Space 80 to 100 feet apart where bedrock is 3 feet or more below surface.

Shallow surface drainage[b]: Space 330 to 660 feet apart where bedrock is less than 3 feet below surface.

Remarks: Bedrock may interfere with grade and alignment. On-site investigation required to determine depth to bedrock.

Soil number and name: **108 Bonnie** **288 Petrolia** **334 Birds**

Subsurface drainage[a]: 3 to 3½ feet deep, 60 to 80 feet apart. Use with surface drainage.

Shallow surface drainage[b]: If necessary, provide surface drainage before installing subsurface drains. Space 330 to 660 feet apart. If land grading is used, spacing may be increased.

Remarks: Bottomland soils subject to overflow unless protected. Subsurface drainage is usually feasible if outlet is available.

DRAINAGE GROUP 3B (moderately slowly permeable, somewhat poorly drained)

Soil number and name:				
	17 Keomah	**257 Clarksdale**	**572 Loran**	**745 Shullsburg**
	46 Herrick	**555 Shadeland**	**743 Ridott**	

Subsurface drainage[a]: 3 to 4 feet deep, 80 to 100 feet apart.

Shallow surface drainage: Use random ditches where depressions occur.

Remarks: Drainage improvement will increase yields in some years. Increase will be smaller and less frequent, however, than on soils in Group 3A. Surface inlets to subsurface drains can sometimes be substituted for surface ditches. Subsurface drains should be installed above shale on Loran, Ridott, Shadeland, and Shullsburg.

Soil number and name:				
	146 Elliott	**189 Martinton**	**337 Creal**	**554 Kernan**
	176 Marissa	**295 Mokena**	**375 Rutland**	

Subsurface drainage[a]: 3 to 3½ feet deep, 70 to 90 feet apart.

Shallow surface drainage: Use random ditches where depressions occur.

Remarks: Drainage improvement will increase yields in some years. Increase will be smaller and less frequent, however, than on soils in Group 3A. Surfce inlets to subsurface drains can sometimes be substituted for surface ditches. Diversions may be useful in some areas.

Soil number and name: **162 Gorham** **589 Bowdre** **619 Parkville**

Subsurface drainage[a]: 3 to 4 feet deep, 120 to 150 feet apart.

Shallow surface drainage: Use random drains where depressions occur.

Remarks: Bottomland soils subject to overflow. Drainage improvement will increase yields in some years. Increase will be smaller and less frequent, however, than on soils in Group 3A. Clayey upper soil and sandy below.

See footnotes on page 4.

DRAINAGE GROUP 4A (slowly and very slowly permeable, poorly or very poorly drained)

Soil number and name:			
229 Monee	**235 Bryce**	**465 Montgomery**	**670 Aholt**
230 Rowe	**238 Rantoul**	**524 Zipp**	

Subsurface drainage[a]*:* Space less than 70 feet apart at depths of 18 to 30 inches. Current studies do not indicate clearly whether subsurface drainage is economical on these soils.

Shallow surface drainage[b]*:* Space 330 to 660 feet apart. If land grading is used, spacing may be increased. On-site assistance needed to determine maximum cut for land grading.

Remarks: Clayey soils. A single subsurface drain with surface inlets may be more economical than surface ditches for depressions.

Soil number and name:			
2 Cisne	**84 Okaw**	**165 Weir**	**287 Chauncey**
12 Wynoose	**109 Racoon**	**206 Thorp**	**460 Ginat**
16 Rushville	**112 Cowden**	**208 Sexton**	**474 Piasa**
26 Wagner	**120 Huey**	**218 Newberry**	**576 Zwingle**
45 Denny	**136 Brooklyn**	**261 Niota**	**633 Traer**
48 Ebbert			

Subsurface drainage[a]*:* Space less than 70 feet apart at depths of 18 to 30 inches. Current studies do not indicate clearly whether subsurface drainage is economical on these soils.

Shallow surface drainage[b]*:* Space 330 to 660 feet apart. If land grading is used, spacing may be increased. On-site assistance needed to determine maximum cut for land grading.

Remarks: Soils with clayey subsoils. A single subsurface drain with surface inlets may be more economical than surface ditches for depressions. Huey and Piasa soils have high sodium content in the subsoil, which may cause silting in drain lines.

Soil number and name: **420 Piopolis**

Subsurface drainage[a]*:* 3 to 3½ feet deep, 60 to 80 feet apart. Use with surface drainage.

Shallow surface drainage[b]*:* Space 330 to 660 feet apart. If land grading is used, spacing may be increased.

Remarks: Bottomland soil. Subject to overflow unless protected.

Soil number and name:			
71 Darwin	**85 Jacob**	**422 Cape**	**457 Booker**
83 Wabash	**404 Titus**	**426 Karnak**	**591 Fults**

Subsurface drainage[a]*:* Space less than 70 feet apart at depths of 18 to 30 inches. Current studies do not indicate clearly whether subsurface drainage is economical on these soils.

Shallow surface drainage[b]*:* Space 330 to 660 feet apart. If land grading is used, spacing may be increased. On-site assistance needed to determine maximum cut for land grading.

Remarks: Clayey bottomland soils. Subject to overflow unless protected. Booker also occurs on low terraces.

Soil number and name: **248 McFain** **590 Cairo**

Subsurface drainage[a]*:* 3 to 4 feet deep, 120 to 150 feet apart.

Shallow surface drainage: Use random ditches where depressions occur.

Remarks: Clayey bottomland soils over sandy material. Subject to overflow unless protected.

See footnotes on page 4.

DRAINAGE GROUP 4B (slowly and very slowly permeable, somewhat poorly drained)

Soil number and name: **3 Hoyleton**, **13 Bluford**, **23 Blount**, **91 Swygert**, **113 Oconee**, **164 Stoy**, **167 Lukin**, **192 Del Rey**, **298 Beecher**, **335 Robbs**, **461 Weinbach**, **517 Marine**, **620 Darmstadt**, **621 Coulterville**, **787 Banlic**

Subsurface drainage[a]*:* Space less than 70 feet apart at depths of 18 to 30 inches. Current studies do not indicate clearly whether subsurface drainage is economical on these soils.

Shallow surface drainage: Surface ditches may serve as outlets for low spots.

Remarks: Random drain lines with surface inlets may be useful as an alternative to surface ditches. Darmstadt soils have high sodium content in the subsoil, which may cause silting in drain lines.

Soil number and name: **147 Clarence**, **173 McGary**, **228 Nappanee**, **262 Denrock**, **320 Frankfort**, **338 Hurst**

Subsurface drainage[a]*:* Space less than 70 feet apart at depths of 18 to 30 inches. Current studies do not indicate clearly whether subsurface drainage is economical on these soils.

Shallow surface drainage: Surface drainage recommended for areas with slopes of less than 1 percent.

Remarks: Soils with clayey subsoils.

Soil number and name: **592 Nameoki**

Subsurface drainage[a]*:* Space less than 70 feet apart at depths of 18 to 30 inches. Current studies do not indicate clearly whether subsurface drainage is economical on these soils.

Shallow surface drainage: Surface ditches may serve as outlets for low spots.

Remarks: Clayey bottomland soils. Subject to overflow unless protected.

See footnotes on page 4.

Outlets for Drainage Systems

To meet its design requirements, a drainage system must have an outlet of adequate capacity, depth, and stability (Figure 1). If the outlet is inadequate, the effectiveness of the entire drainage system can be greatly reduced or lost. An outlet channel must have the capacity to carry flow not only from the drainage system but also from the entire area served by the system. Where the outlet carries flow from subsurface drains, the outlet should be deep enough that the drains can be discharged into it above normal low-water flow.

Installation of an outlet channel or improvement of an existing channel usually increases peak discharge downstream from the end of the improvement. Take steps to prevent increased stages downstream from creating significant damage. The channel must be stable when flow reaches design capacity. Where the drainage area exceeds 1 square mile, consult *Design of Open Channels,* Soil Conservation Service Technical Release no. 25, U.S. Department of Agriculture, Washington, D.C., October 1977. This publication contains procedures for evaluating channel stability.

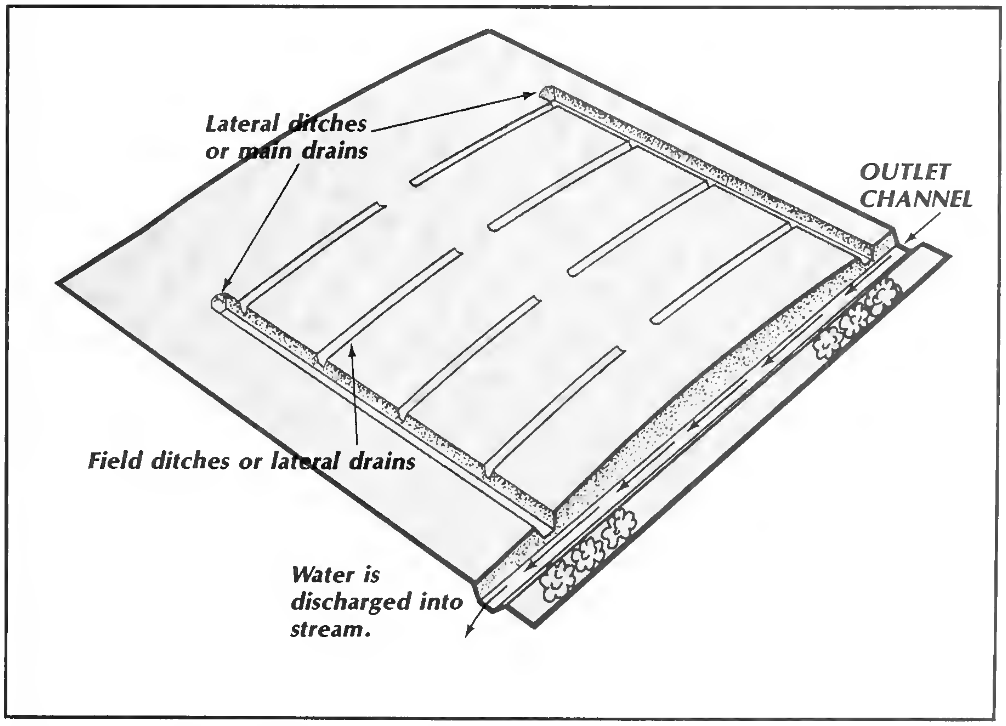


Figure 1. Systematic drainage. An adequate outlet is very important to the effectiveness of a drainage system. Any part or all of the system pictured could be a surface ditch or subsurface drain.

Design considerations

Capacity

Crops can tolerate a limited amount of flooding or ponding but should normally not be flooded or ponded for longer than 24 to 48 hours. To determine what the capacity of the outlet channel must be to remove water quickly enough, either calculate flood routings of the drainage area or refer to drainage curves like those shown in Figure 2. The curves show the rate of discharge that will provide a certain level of drainage in the watershed area. They were developed from many field measurements of drainage flow rates and from observation of drainage systems. The curves are applicable only to drainage areas having average slopes of less than 25 feet per mile and do not allow for peak flows after heavy rains. Excess runoff will be discharged overland, temporarily flooding adjacent areas.

Outlet channels designed according to **curve B** will provide excellent agricultural drainage in Illinois. Use this curve for drainage of truck crops, nursery crops, and other specialty crops. Designs based on curve B will provide the best drainage that can normally be justified in agricultural areas. Channels that are designed according to **curve C** will provide good agricultural drainage in Illinois. This curve is the one most often recommended for drainage of Illinois cropland. Designs based on **curve D** provide satisfactory agricultural drainage as long as frequent overflow does not cause excessive damage. This curve is generally recommended for pasture or woodland. It may also be adequate for drainage of general cropland in northern Illinois, provided that the landowner carries out an excellent maintenance program. Designs based on curve D provide the minimum amount of drainage recommended in Illinois.

Once you know what the capacity of the outlet channel must be, you need to determine the size that will enable it to convey the desired amount of flow without letting the water surface rise above a predetermined elevation. The following sections describe some basic hydraulic concepts that will help you design a channel of the proper size.

Velocity

The velocity of water flow must be high enough to prevent siltation in the channel but low enough to avoid erosion. Listed on the next page are the maximum velocities for drainage areas of 640 acres or less. The velocity should be no lower than 1.5 feet per second. A lower velocity will

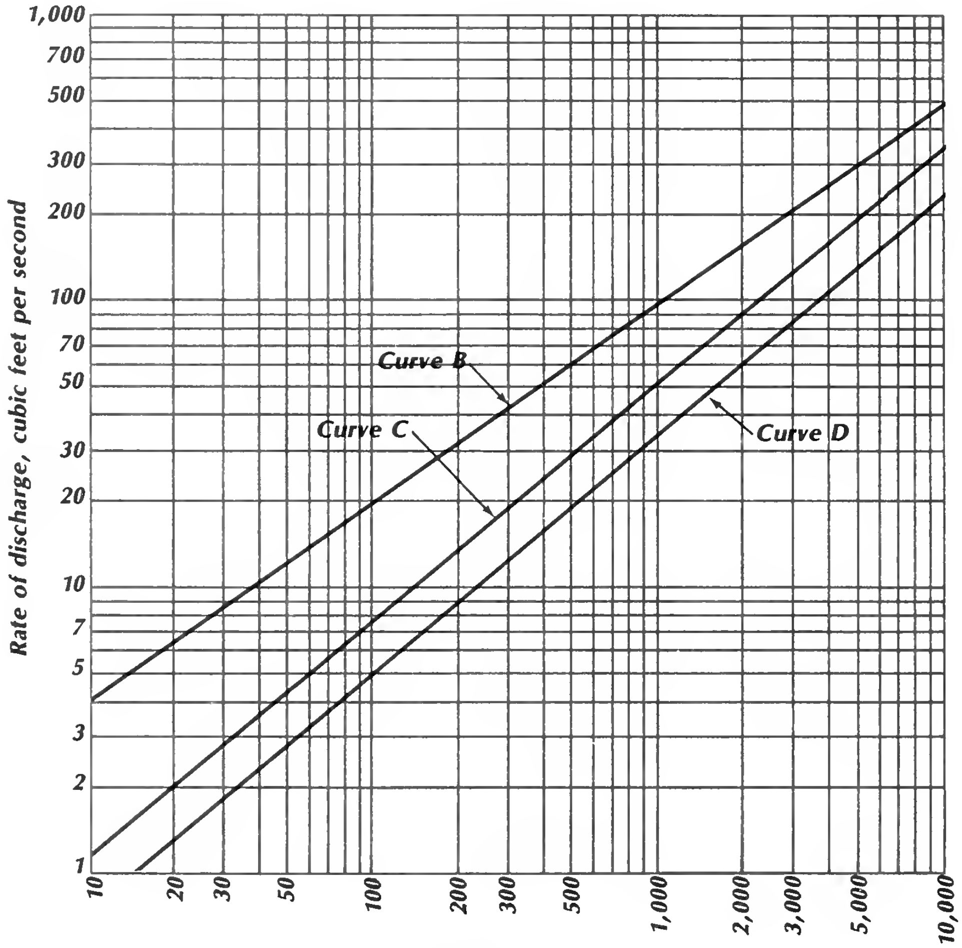


Figure 2. Drainage curves for determining what the capacity of an open ditch must be to provide a certain level of drainage in a specified area. Channels based on curve B *provide excellent agricultural drainage; those on curve* C, *good drainage; and those on curve* D, *satisfactory drainage. (Adapted from Soil Conservation Service,* National Engineering Handbook, *Section 16, Chapter 5.)*

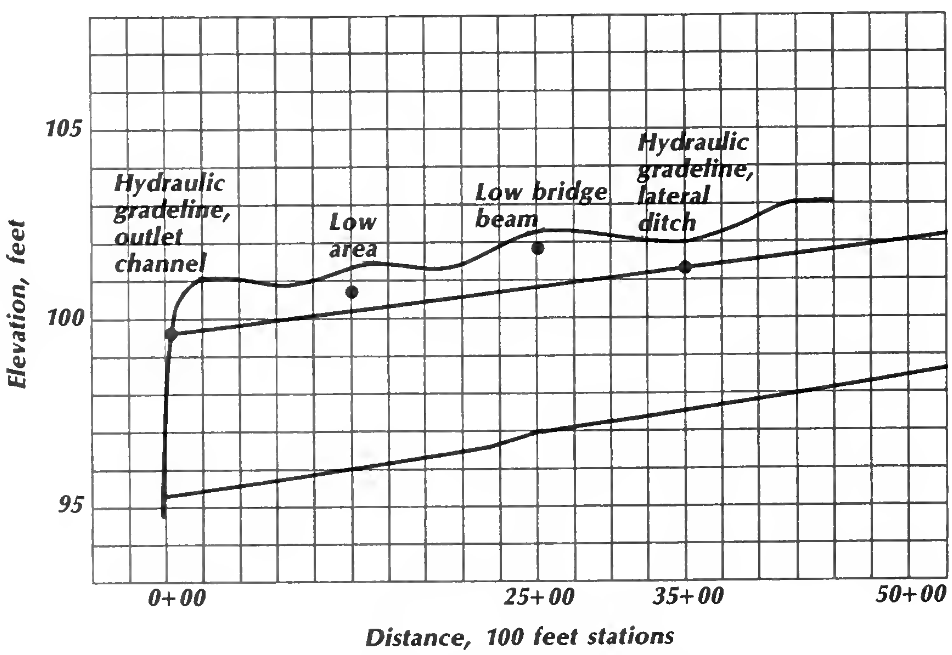


Figure 3. Profile of an outlet channel showing the hydraulic gradeline designed through or below critical control points.

cause siltation, which encourages moss and weed growth and reduces the cross section of the channel.

Soil texture	Maximum velocity, ft/sec
Sand or sandy loam	2.5
Silt loam	3.0
Sandy clay loam	3.5
Clay loam	4.0
Clay or silty clay	5.0
Fine gravel, cobbles, or graded loam to cobbles	5.0
Graded mixture silt to cobbles	5.5
Coarse gravel, shales, or hardpans	6.0

Hydraulic gradient

The hydraulic gradient represents the surface of the water when the outlet channel is operating at its design flow (Figure 3). The hydraulic gradient for the channel should be determined from control points such as the elevation of low areas served by the channel and the hydraulic gradients of tributary ditches. Draw the hydraulic gradient through or below as many important control points as possible after studying the profile of the natural ground surface, elevations established by surveys, and channel restrictions such as culverts and bridges.

If you estimate the elevations of control points rather than compute them from survey data, the hydraulic gradeline should be no less than 1 foot below fields that will receive runoff from ditches draining more than 640 acres, 0.5 foot for ditches draining 40 to 640 acres, and 0.3 foot for ditches draining less than 40 acres. For lands planted in only water-tolerant vegetation, such as some trees and grasses, these requirements may be modified and the hydraulic gradeline set at ground level. These guidelines do not apply to channels where flow is contained by dikes.

Manning's equation

The most widely used equation for designing outlet channels was developed by Robert Manning in 1890 and is known as Manning's equation:

$$V = \frac{1.486}{n} r^{2/3} s^{1/2}$$

where
- V = average velocity of flow in feet per second,
- n = coefficient of roughness,
- r = hydraulic radius in feet,
- s = slope of hydraulic gradient in feet per foot (although s should be the slope of the water surface, it can be the slope of the channel bottom for designs within the scope of this publication).

The equation below is used to determine r:

$$r = \frac{A}{p}$$

where
- A = area of cross section in square feet,
- p = wetted perimeter or length, in feet, of cross section on which water impinges.

The roughness coefficient n takes into account not just roughness, but anything in a channel that might retard the flow of water. Vegetation, meanders, obstructions, etc., all affect channel flow. For designs within the scope of this publication, a value of n = 0.04 is commonly used if the channel has aged. Many tables used in channel design are based on that value. However, in determining a value for n, you should consider all retarding influences, not just aging. Select a value representing conditions that will exist after the channel has aged and that assumes the amount of maintenance you expect to do.

Generally, n tends to decrease as the hydraulic radius increases. Listed below are recommended values for n based on the hydraulic radius of the channel. You can use these values in solving Manning's equation if the channel has good alignment.

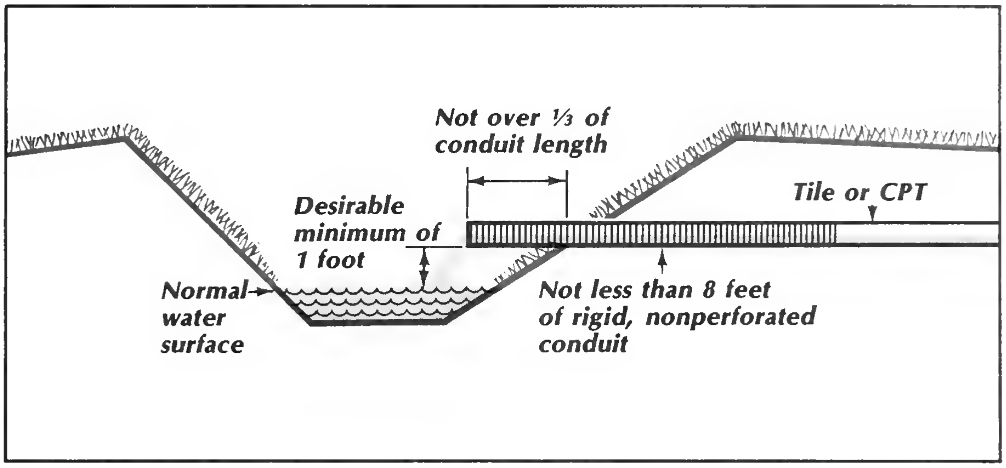


Figure 4. Entrance of a subsurface drain into an outlet channel.

Hydraulic radius	n
less than 2.5	.040 to .045
2.5 to 4.0	.035 to .040
4.1 to 5.0	.030 to .035
more than 5.0	.025 to .030

After determining V, calculate channel capacity, using the continuity equation:

$$Q = A \times V$$

where
- Q = capacity in cubic feet per second,
- A = area of cross section in square feet,
- V = velocity in feet per second (determined from Manning's equation).

The references listed below contain tables that will aid you in solving Manning's equation:

King, Horace Williams, and Ernest F. Brater. *Handbook of Hydraulics.* 5th ed. New York: McGraw-Hill, 1977.

Army Corps of Engineers. *Hydraulic Tables.* 2nd ed. Washington, D.C.: U.S. Government Printing Office, 1944.

Bureau of Reclamation, *Hydraulic and Excavation Tables.* 11th ed. 1957. Reprint. Washington, D.C.: U.S. Government Printing Office, 1974.

Channel depth

An outlet channel that receives water from subsurface drains should be designed to keep the normal water surface 1 foot below the bottom of the subsurface drain (Figure 4). The normal water surface is defined as the elevation of the usual low flow during the growing season. The clearance may be less where there are unusual site conditions.

Cross section

The design cross section of the outlet channel should meet the combined requirements of capacity, velocity, depth, side slopes, and bottom width, and, if necessary, allow for initial sedimentation. The side slopes should be stable, meet maintenance requirements, and be designed according to site conditions. In silt, the side slopes should be no steeper than 2 to 1; in clay and other heavy soils, 1½ to 1; and in sands, peat, and muck, 1 to 1.

Construction equipment and maintenance requirements influence the width of the bottom of the channel and should be determined according to the conditions of the site.

Other considerations

Location and alignment

If possible, the outlet channel should be located near or parallel to field boundaries or property lines where it will not interfere with cropping patterns. It is even more desirable to place it along existing natural drainage courses to minimize excavation.

We recommend that you lay out the channel in straight lines and gentle curves. Table 1 lists recommended minimum radii of curvature for channels without bank protection. Provide bank protection if changes in alignment are sharper than those listed in the table.

Table 1. Minimum Radii of Curvature without Bank Protection

Width of ditch top, feet	Slope, feet/mile	Minimum radius of curvature, feet	Approximate degree of curve
Small ditch (less than 15)	Under 3	300	19
	3 to 6	400	14
Medium ditch (15 to 35)	Under 3	500	11
	3 to 6	600	10
Large ditch (greater than 35)	Under 3	600	10
	3 to 6	800	7

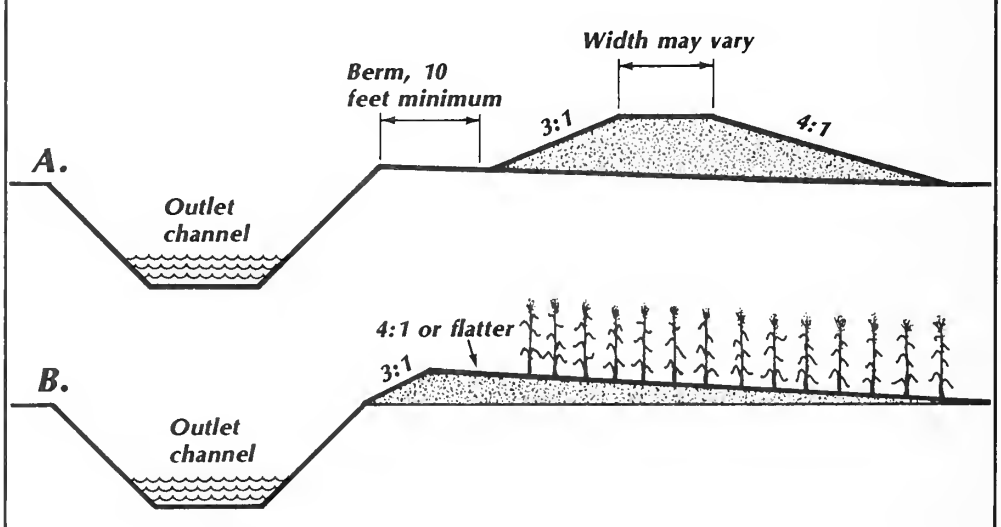


Figure 5. In drawing A, excavated soil (shaded area) has been placed in a spoil bank and a berm has been created. In B, the spoil has been spread without a berm. Spoil may be spread on either or both sides of an outlet channel.

Berms and spoil banks

Excavated soil may either be spread or placed in spoil banks along the outlet channel. If you place the soil in spoil banks, also leave a berm or flat area adjacent to the channel bank for the construction of roads and operation of maintenance equipment. Berms will also prevent excavated material from rolling back into the channel and lessen sloughing of the banks by reducing heavy loads on them. Berms should be at least 10 feet wide, and, if the channels are over 8 feet deep, they should be 15 feet wide (Figure 5a). Make sure that the side slopes of the spoil banks are stable and adequately shaped to permit establishment and maintenance of vegetation. Provide some means by which water can flow through the spoil and into the ditch without causing erosion.

On cropland it is often desirable to spread the spoil. Begin spreading at or near the channel bank or leave a berm as described above. If you begin spreading at the channel bank, carry the spoil upward at a slope no steeper than 3 to 1 to a depth no greater than 3 feet. From the point of maximum depth, the spoil should be graded to slope away from the channel no steeper than 4 to 1 and preferably 8 to 1 if the spoil is to be farmed (Figure 5b).

Junctions of lateral ditches

Where there is a significant drop from a lateral ditch to the outlet channel, the lateral should be cut back on a level grade and then graded back on a slope (Figure 6a). The purpose of this level area is to store sediment and protect the channel until the lateral stabilizes. Excavate the lateral on a level grade flush with the bottom of the outlet ditch for a distance of 50 to 300 feet. Then, steepen the lateral grade from 0.5 to 1.0 percent until it intersects the normal grade of the lateral. Where the drop from the lateral to the channel is too great to be controlled by the above method, you will have to provide structural protection.

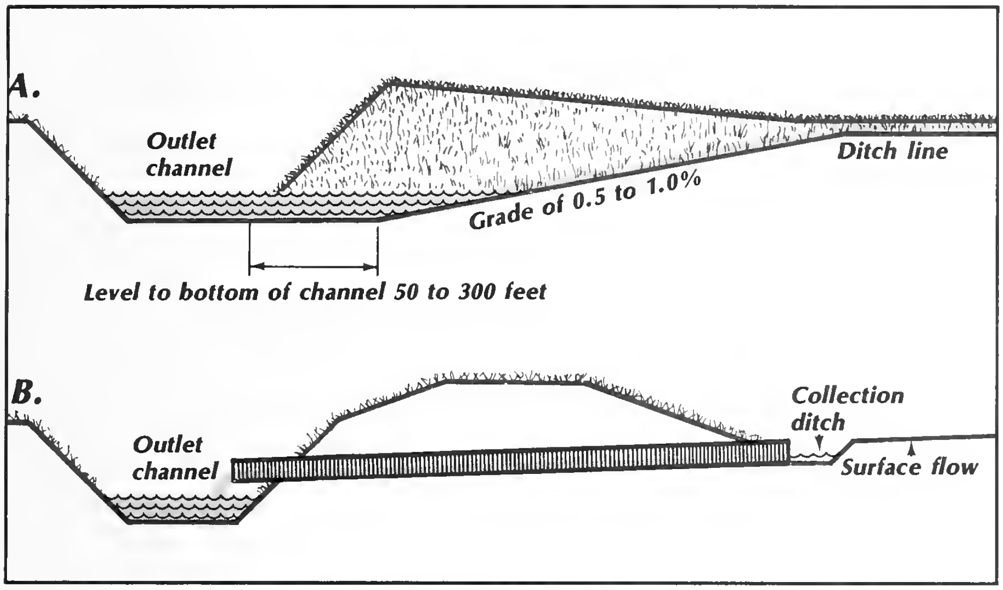


Figure 6. Drawing A shows a lateral ditch graded through a spoil bank to discharge directly into an outlet channel. Drawing B shows how a pipe can be used to move water through a spoil bank to an outlet channel.

Structural protection
Ideally, surface water should enter the outlet channel only through lateral ditches graded to the bottom of the channel (Figure 6a) or through stabilizing structures such as chutes, drop spillways, or conduits with proper inlets (Figure 6b). These structures may be located at the entrances of lateral ditches, at the heads of outlet channels, or along the outlet channel at selected intervals.

Culverts and bridges
When designing culverts and bridges across ditches, carefully determine the load from the weight of farm machinery, trucks, and other vehicles expected to cross them. Designs should facilitate ditch maintenance around the abutments, and the openings must be large enough not to reduce ditch flow capacity. Where it is not possible to construct bridges and culverts, you can build fords with ramps for livestock and machinery.

Effects on environment
In most cases, you can build and maintain an outlet channel that will accomplish its purpose as well as contribute to the environment. For example, if a dense tree canopy is situated on the site of the channel, you can carry out construction from just one side of the channel. The canopy remaining will shade the channel for at least part of the day. The favorable effects of the tree canopy will be to provide a windbreak; increase the fishery potential of the channel by keeping the water temperature lower than if the channel were unshaded; provide an area for wildlife between the cropped area and the water; and create a pleasing esthetic effect on land that might otherwise have been committed entirely to agricultural use.

Delay mowing in the channel and on maintenance travelways until the ground-nesting species of wildlife have departed, which is normally after the middle of July. Areas along the channel that are not used for travel or farming can be planted to shrubs, trees, or other plants that provide food for wildlife.

Maintenance

Maintenance of a drainage system is the key to lengthening its life and lowering operating costs. In any proposed drainage project, you should begin thinking about maintenance requirements as early as the design stage. We strongly recommend a systematic, annual inspection and maintenance program.

Seeding outlet channel banks to permanent cover will prolong the life of many channels by helping to stabilize the banks and by reducing weed infestations. Maintain a 10-foot grass strip along the channel to reduce erosion and provide access for maintenance. Brush and weeds reduce the velocity of water flowing in the channel, limiting its drainage capacity. Short-stemmed grasses are preferred since they provide a smooth surface for water. The grass on channel banks, berms, and spoil banks may occasionally need mowing. When you mow, be careful to avoid destroying wildlife. Brush and weeds can be controlled by herbicide sprays. Always check local, state, and federal regulations on the use of herbicides, and be sure to follow the instructions on the herbicide label.

Aquatic weeds should be kept out of channel bottoms since weeds limit drainage by reducing flow rates and causing sediment to deposit. Although these weeds can be controlled with herbicides, whether you may apply them will depend upon downstream uses of the water and your legal liability. Be sure to investigate your legal liability before applying herbicides. Sediment deposits and accumulations of debris should be removed from outlet channels to maintain their design capacity.

Surface drainage is the removal of water that collects on the land surface. A surface drainage system consists of shallow ditches and should include land smoothing or land grading. This type of system is suitable for all slowly permeable soils and for soils with fragipans or clay subsoils.

The rate at which water is removed by surface drainage depends on several interrelated factors, including rainfall, soil properties, and cropping patterns. For most row crops, a surface drainage system should remove excess water within 24 to 48 hours. More rapid removal may be necessary for higher value truck crops.

Before designing a surface drainage system, you should make a topographic survey and develop a contour map of the area, using grid surveys, laser techniques, photogrammetric methods, or some combination of these. Keep copies of the contour maps, as-built plans, and profiles as a record of permanent improvements. These resources will be invaluable later when the ditches have to be reshaped or the channel regraded.

Components

A surface drainage system consists of an outlet channel, lateral ditches, and field ditches. Water is carried to the outlet channel by lateral ditches, which receive water from field ditches or sometimes from the surface of the field.

Plan a minimum number of field ditches located, where possible, at right angles to the lateral ditch and crop rows. It is essential that lateral ditches be deep enough to drain the field ditches completely enough to permit crossing by farm machinery. The minimum depth of lateral ditches is 1.0 foot. At points where lateral ditches enter the outlet channel, grade back small overfalls on a nonerosive grade (Figure 6a). If the outlet is too deep or some other problem makes it difficult to grade the overfall, install a chute, drop spillway, or pipe (Figure 6b).

Two common types of field ditches are the single ditch and the W ditch (also called the twin or double ditch). The single ditch is used where spoil can be moved and spread in low areas of the field without obstructing flow into the ditch. The double or W ditch (illustrated in Figure 7) is used where the land drains towards the ditch from both directions, where the land is very flat and row drainage will enter from each side, and where the excavated material is not needed to fill depressions.

The cross section of a single ditch is usually trapezoidal or V-shaped, as shown in Figure 8. Its minimum depth should be 6 inches for trapezoidals and 9 inches for V sections, each having a minimum cross sectional area of 5 square feet. Field ditches should ordinarily not be deeper than 1 foot where they are to be crossed frequently by farm machinery. Side slopes should be 8 to 1 or flatter for a trapezoidal section and 10 to 1 for V sections.

The cross section of the W ditch system is similar to that of the single ditch, except that if farm machinery is not expected to cross the ditch the side slopes toward the field should be 8 to 1 and those on the crowned section 4 to 1. The excavated earth

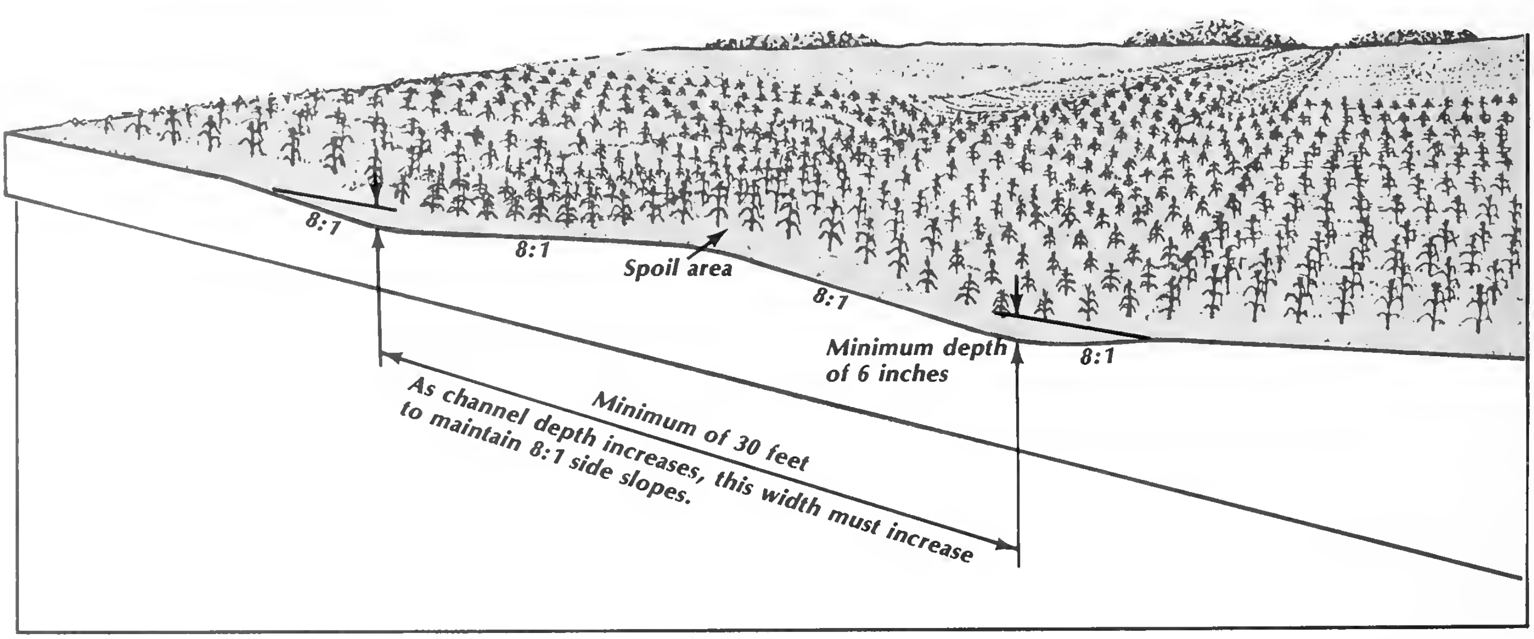


Figure 7. Layout of a W ditch.

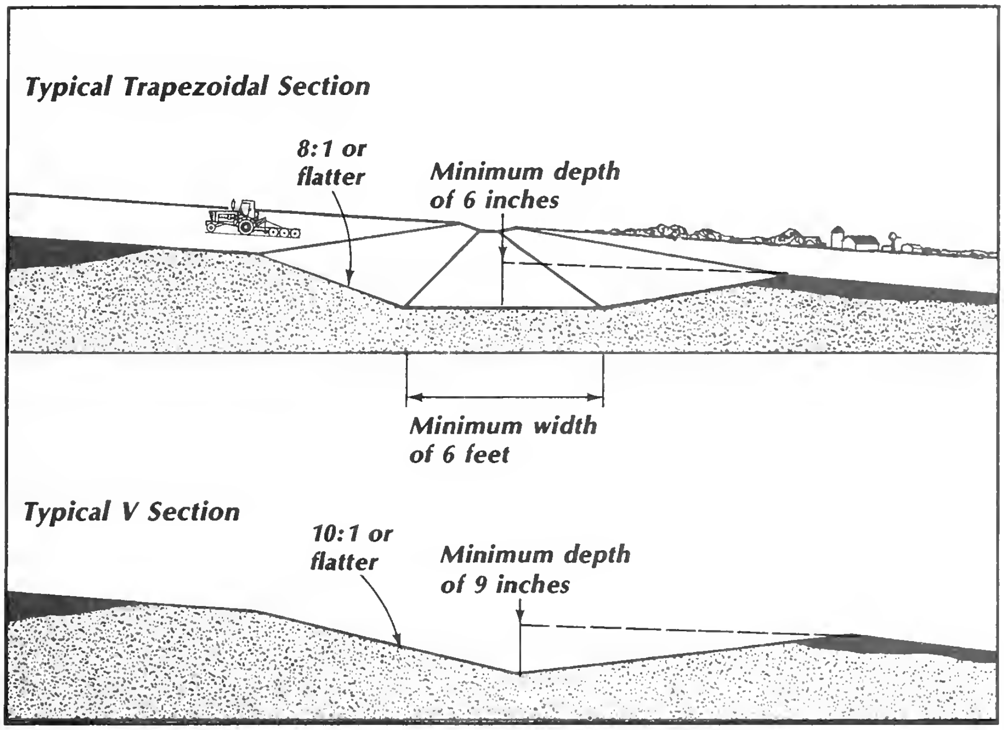


Figure 8. Two typical cross sections of a field ditch. Note how excavated soil (darker areas) from the ditch has been used to fill depressions and to shape land areas adjacent to the ditch.

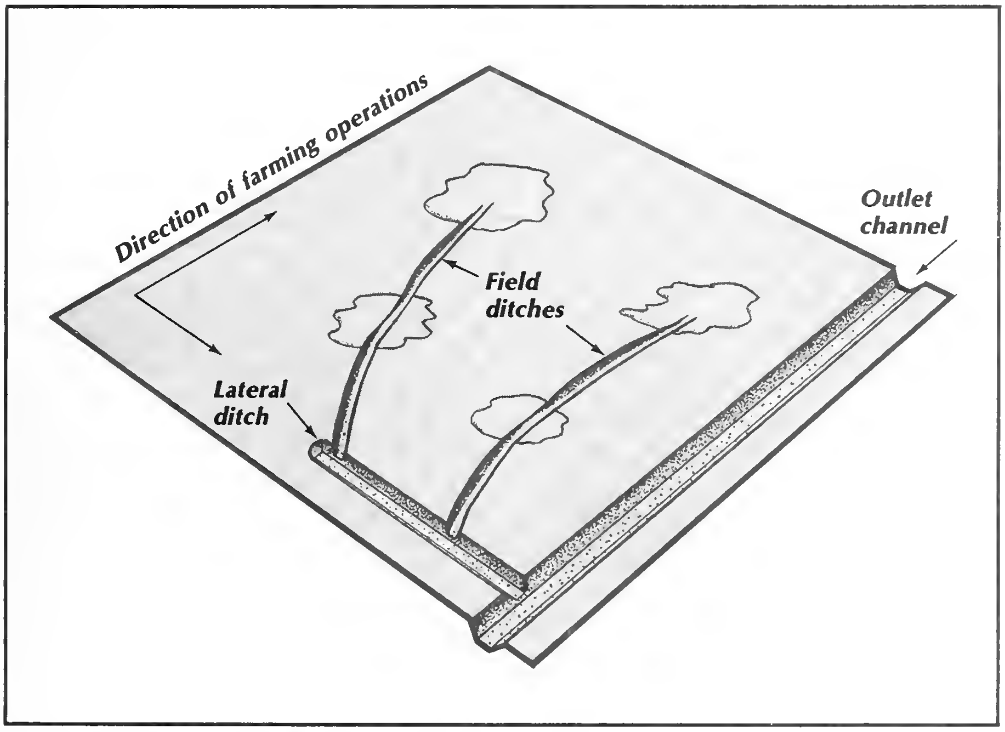


Figure 9. Random ditch pattern for surface drainage.

should be shaped into a crowned section between the two ditches. The crowned section should be large enough to accommodate the spoil that has been removed. The minimum distance between ditch centers should be 30 feet. Determine the capacity of the ditches according to curve B or C in Figure 2. The minimum recommended design grade is 0.1 foot per 100 feet. Where the channel grade is less than 0.05 foot per 100 feet, ponding and siltation may occur.

Diversions may be included in a drainage system to prevent surface runoff from sloping land from reaching a flat or depressional area. Diversion ditches are located at the base of a slope to intercept and carry surface flow to an outlet. Their side slopes range between 2 to 1 and 4 to 1, and they should be kept in sod. To minimize overtopping of the diversion, design the ditch cross section to carry the runoff from a 10-year frequency storm of 24-hour duration.

Patterns

The two main types of surface drainage patterns are random and parallel. Each includes lateral ditches that permit water to flow from the drainage system to a suitable outlet. The pattern you choose depends upon the soil type and topography of the land.

Random

The random ditch pattern is adapted to slowly permeable soils having depressional areas that are too large to be eliminated by land smoothing or grading. Field ditches connect the major low spots and remove excess surface water from them. They are generally shallow enough to permit frequent crossing by farm machinery. Soil from the ditches can be used to fill minor low spots in the field.

Field ditches should extend through most of the depressions, as shown in Figure 9, to assure complete drainage, and they should follow the natural slope of the land in accordance with Illinois drainage law.

Parallel

The parallel ditch pattern is suitable for flatter, poorly drained soils that have numerous shallow depressions (Figure 10). In fields that can be cultivated up and down slope, parallel field ditches are installed across the slope to break the field into shorter units of length and make it less susceptible to erosion. The field should be farmed in the direction of the greatest slope. Dead furrows are neither desirable nor necessary.

Although the ditches must be parallel, they need not be equidistant. The spacing between them depends upon the permissible length of row drainage for the soil type and upon the amount of earth and the distance it must be moved to provide complete row drainage. The maximum length of the grade draining to a ditch should be 660 feet.

The success of a surface system using a parallel pattern depends largely upon proper spacing of the parallel ditches and the smoothing or grading between them. During the grading operation, fill all depressions and remove all barriers. Excavated material from ditches can also be used as fill for establishing grades.

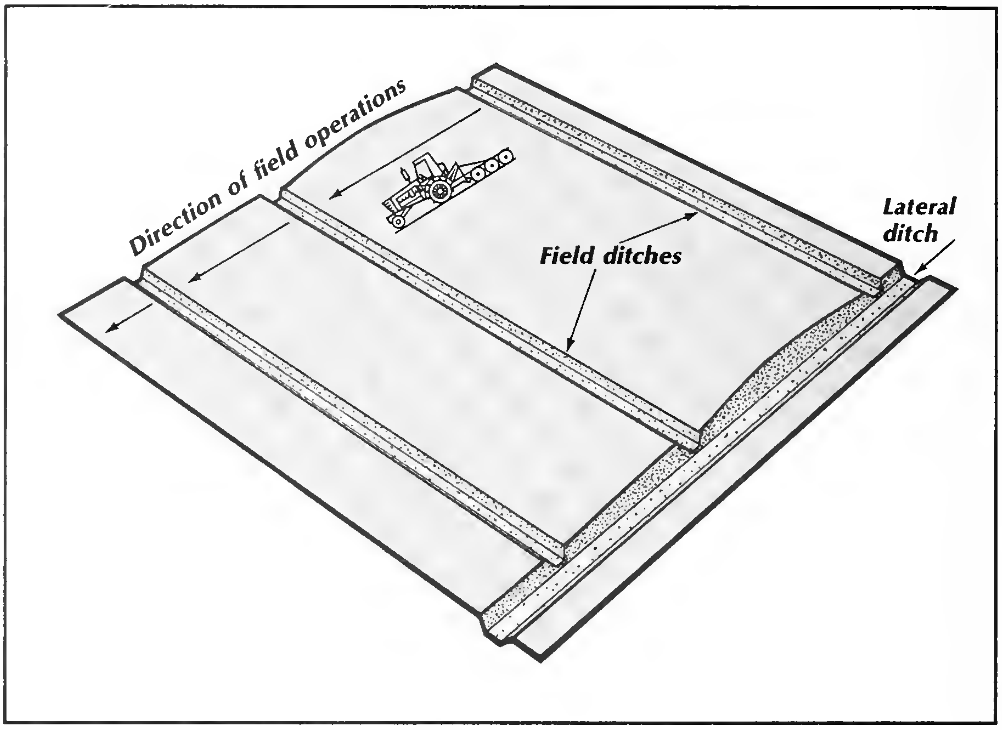


Figure 10. Parallel ditch pattern for surface drainage.

Shaping the surface

Grading

Land grading (also termed precision land forming) is the reshaping of the surface of land with tractors and scrapers to planned grades. Its purpose is to provide excellent surface drainage although the amount of grading will depend upon the soil and costs. To do a good job of land grading, you need a detailed engineering survey and construction layout.

To assure adequate surface drainage, eliminate all reverse surface grades that form depressions. The recommended surface grades range from 0.1 to 0.5 percent and may be uniform or variable. The cross slopes normally should not exceed 0.5 percent. Minimum grade limits should include a construction tolerance that will permit the elimination of all depressions either in original construction or in postconstruction touchup. Reverse grades can be eliminated with relative ease in a field that has minimum grades of 0.2 percent. Unusual precision in construction is required to eliminate reverse surface grades in fields that have 0.1 percent and flatter grades.

Land grading is hampered by trash and vegetation. This material should be destroyed or removed before construction and kept under control while the work is being done. The fields should be chiseled before construction if there are hardpans. The field surface should be firm when it is surveyed so that rod readings taken at stakes will reflect the true elevation. Do not grade fields when they are wet because working wet soil impairs the physical condition of the soil.

Smoothing

Land smoothing removes irregularities on the land surface and should be done after land grading and may be useful in other situations. Special equipment such as a land plane or land leveler is used. The purpose of land smoothing is to improve surface drainage. The smoothing operation may ordinarily be directed in the field without detailed surveys or plans, although grid surveys may be needed for some critical parts of the field.

A smoothing operation consists of a minimum of three passes with a land leveler. Make the first two passes on opposite diagonals

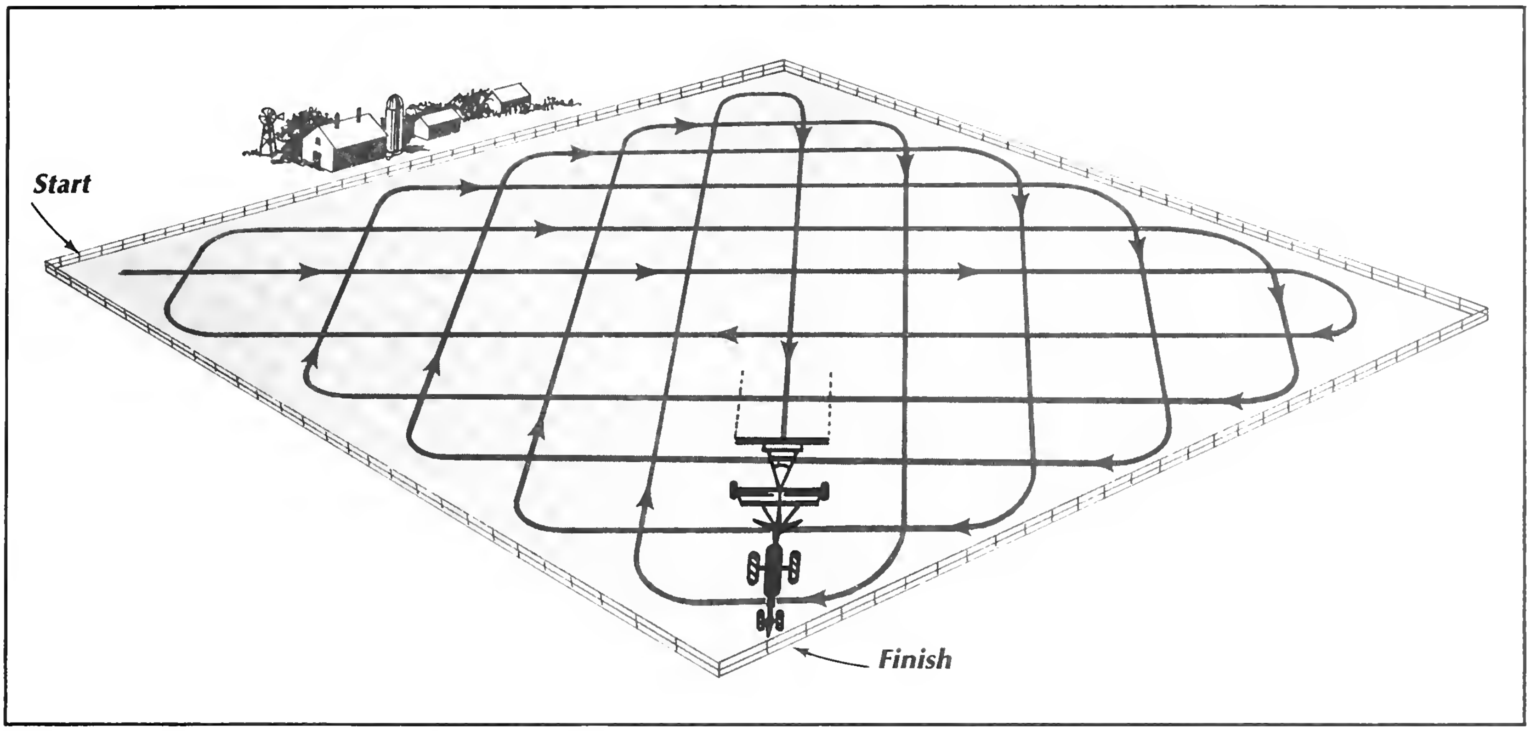


Figure 11. Suggested procedure for a land smoothing operation.

as noted in Figure 11 and the last pass in the direction of cultivation. Either before or after the final land smoothing operation, chisel fields to loosen the cut surfaces and to blend the fill material with the underlying soil. The finished surface should be free from minor depressions so that runoff will flow unobstructed to field or lateral ditches.

Maintenance

The outlet channel, lateral ditches, and field ditches should be cleaned as needed to keep them functioning properly. Small deposits of silt often greatly reduce the capacity of a surface drainage system and cause partial or complete failure of it. After each heavy rain, the outlet channel and ditches should be inspected, and silt deposits or other obstructions removed. Brushy types of vegetation, such as cattails, willows, and cottonwoods, are a menace to surface ditches and should be cut or sprayed once or twice each year as needed.

Maintenance of areas that have been graded is critical during the first year or two after construction. Settlement of the fill areas may make several annual land smoothing operations necessary. In some cases, particularly where deep fill has been made, it may be necessary to cut and fill again, using tractors and scrapers to eliminate depressions and reverse surface grades. It is suggested that after each plowing a land plane be operated over the area at least twice, making one pass along each diagonal (Figure 11). This operation will not only take care of settlement in the field areas and erase all scars to the land surface caused by field operations but also provide a good seedbed.

Subsurface Drainage

Subsurface drainage is used where the soil is permeable enough to allow economical spacing of the drains and productive enough to justify the investment. A subsurface drain will provide trouble-free service for many years as long as it is carefully planned, properly installed, and constructed of high-quality materials.

Components

A subsurface drainage system consists of a surface or subsurface outlet and subsurface main drains and laterals. Water is carried into the outlet by main drains, which receive water from the laterals. Submains are sometimes used off the main drain to collect water.

The system will function only as well as its outlet. When planning a subsurface drainage system, make sure that a suitable surface or subsurface outlet is available or can be constructed. Where a surface outlet channel is used, all subsurface drains emptying into the outlet should be protected against erosion, against damage that occurs during periods of submergence, against damage caused by ice and floating debris, and against entry of rodents or other animals.

An older subsurface outlet used for a new subsurface drainage system should be free from breakdowns, fractured tile, excessive sedimentation, and root clogging. It must be deep enough to intercept all outletting main drains and laterals and have sufficient capacity to handle the flow. It must also be deep enough to provide the minimum recommended cover for all drains newly installed or intercepted.

If no suitable outlet is available and it is not practical to improve an existing ditch, you might consider using pump outlets. See page 43 for a discussion of pump capacity and design.

Site considerations

In planning a subsurface drainage system, you need to determine the topography of the site to be drained, keeping in mind the depth limitations of the trenching machines and the amount of soil cover required over the drains. The amount of surveying you must do to obtain topographic information depends on the lay of the land. Where the slope of the land is obvious, only a limited amount of data is needed to locate the drains. A topographic survey is necessary, however, for flat and slightly undulating land since it is not as obvious where drains ought to be located. Obtain enough topographic information so that you can plan the entire system before installing it. Planning the job without first gathering enough data often results in a piecemeal system that may eventually be very costly.

The type of subsurface drainage system you install depends to a large degree upon the soils in the area to be drained. Knowing the soil types also helps you anticipate special drainage problems. To identify the soils, refer to soil maps that are available at local offices of the Soil Conservation Service and the Cooperative Extension Service. You can supplement the map information by taking soil borings and digging test pits. Once the soils have been identified, refer to pages 4 to 8 for drainage recommendations.

Also in planning a subsurface system, keep in mind that trees such as willow, elm, soft maple, and cottonwood should be removed for a distance of approximately 100 feet on either side of a subsurface drain line. All other species of trees, except, possibly, fruit trees, should be removed for a distance of 50 feet. If the trees cannot be removed, plan to reroute the line or to use nonperforated tubing or tile with sealed joints throughout the root zone of the trees.

Patterns

Because subsurface drainage is used primarily to lower the water table or remove excess water that is percolating through the soil over a general area, the drains are placed in a pattern determined by the characteristics of the area.* If the soil is homogeneous, the water table is lowered at about the same rate on both sides of each drain. Flow from the drains is generally intermittent.

Four basic patterns are used in the design of subsurface drainage systems. Select the pattern that best fits the topography of the land, that can be located near enough to the sources of excess water, and that is suited to other field conditions. The four basic patterns are illustrated in Figure 12.

Random

The random pattern is suitable for undulating or rolling land that contains isolated wet areas. The main drain is usually placed in the swales rather than in deep cuts through ridges. The laterals in this pattern are arranged according to the size of the isolated wet areas. Thus, the laterals may be arranged in a parallel or herringbone pattern or may be a single drain connected to a submain or the main drain.

Parallel

The parallel pattern consists of parallel lateral drains located perpendicular to the main drain. The laterals in the pattern may be spaced at any interval consistent with site conditions. This pattern is used on flat, regularly shaped fields and on uniform soil. Variations of this pattern are often combined with others.

* The lowering of the water table over a general area is often called relief drainage.

Herringbone

The herringbone pattern consists of parallel laterals that enter the main at an angle, usually from both sides. The main is located on the major slope of the land, and the laterals are angled upstream on a grade. This pattern is often combined with others to drain small or irregular areas. Its disadvantages are that it may cause double drainage (since two field laterals intercept the main at the same point) and that it may cost more than other patterns because it contains more junctions. Nevertheless, the herringbone pattern can provide the extra drainage needed for the less permeable soils that are found in narrow depressions.

Double main

The double main pattern is a modification of the parallel and herringbone patterns. It is applicable where a depression, frequently a watercourse, divides the field in which drains are to be installed. This pattern also is sometimes chosen where the depressional area is wet because of seepage coming from higher ground. Placing a main on each side of the depression serves two purposes: the main intercepts the seepage water, and it provides an outlet for the laterals. If the depression is deep and unusually wide and if you place only one main in the center, you may have to make a break in the gradeline of each lateral before it reaches the main. By locating a main on each side of the depression, you can keep the gradeline of the laterals more uniform.

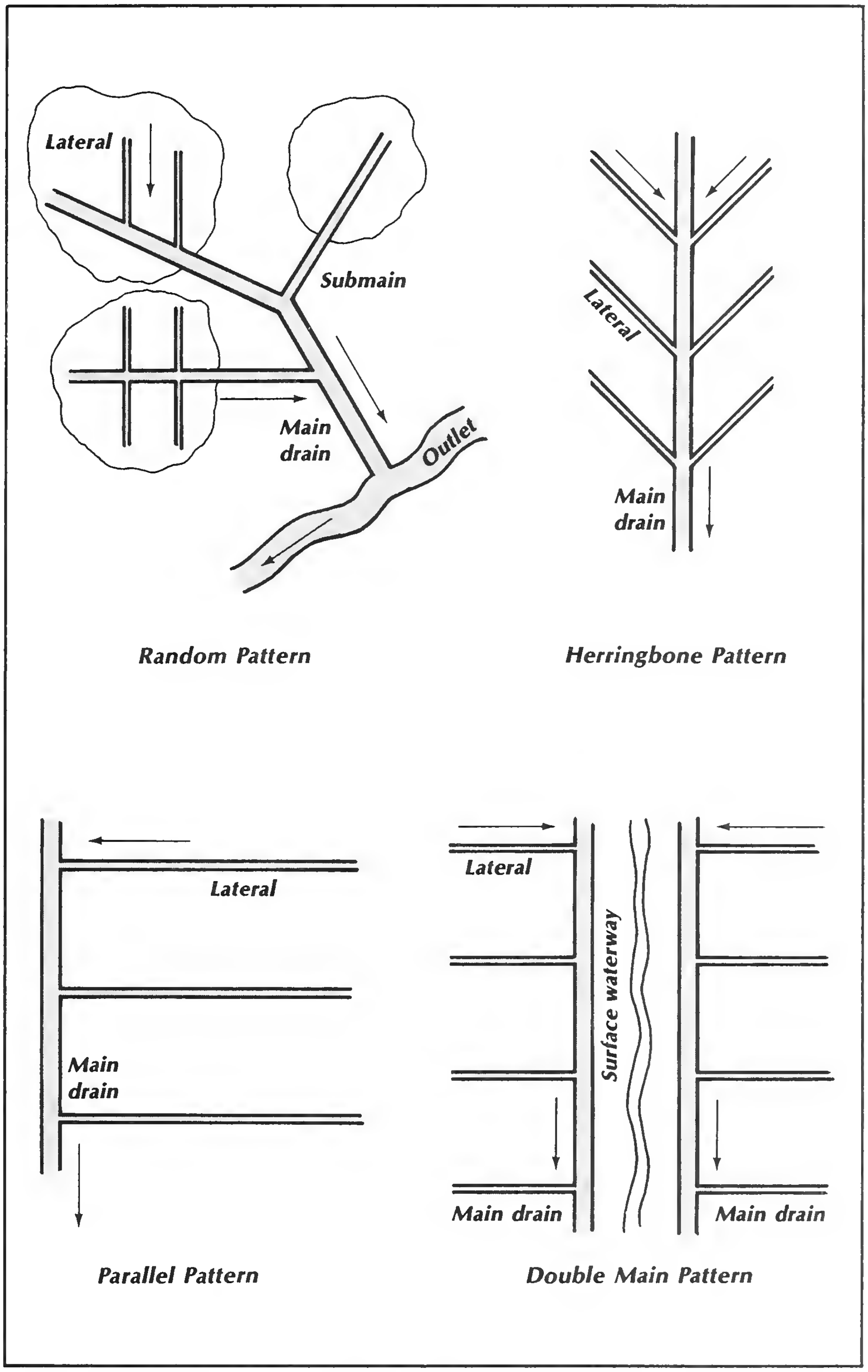


Figure 12. Basic patterns for subsurface drainage systems (the arrows indicate the direction of water flow).

Materials

Material specifications for drain conduits benefit both the drainage contractor and landowner. These specifications enable manufacturers to maintain uniformity in their products, thus giving buyers some assurance that the products will be strong and durable and perform adequately in drainage systems. The materials used for subsurface drainage include clay, concrete, bituminized fiber, metal, plastic, and other materials of acceptable quality. Current specifications for these materials can be obtained from the American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, Pennsylvania 19103. The ASTM designations for these specifications are listed opposite and in Section IV of the *Technical Guide,* which is prepared by the Soil Conservation Service. Use these or federal specifications in determining the quality of a conduit.

Materials for Subsurface Drainage

Material	Specification
Clay drain tile	ASTM[a] C 4
Clay drain tile, perforated	ASTM C 498
Clay pipe, perforated, standard, and extra-strength	ASTM C 700
Clay pipe, testing	ASTM C 301
Concrete drain tile	ASTM C 412
Concrete pipe for irrigation or drainage	ASTM C 118
Concrete pipe or tile, determining physical properties of	ASTM C 497
Concrete sewer, storm drain, and culvert pipe	ASTM C 14
Reinforced concrete culvert, storm drain, and sewer pipe	ASTM C 76
Perforated concrete pipe	ASTM C 444
Portland cement	ASTM C 150
Asbestos-cement storm drain pipe	ASTM C 663
Asbestos-cement nonpressure sewer pipe	ASTM C 428
Asbestos-cement perforated underdrain pipe	ASTM C 508
Asbestos-cement pipe, testing	ASTM C 500
Pipe, bituminized fiber (and fittings)	SS-P-1540[b]
Homogeneous bituminized fiber pipe for general drainage	ASTM D 2311
Homogeneous bituminized fiber pipe, testing	ASTM D 2314
Laminated-wall bituminized fiber perforated pipe for agricultural, land, and general drainage	ASTM D 2417
Laminated-wall bituminized fiber pipe, physical testing of	ASTM D 2315
Styrene rubber plastic drain pipe and fittings	ASTM D 2852
Polyvinyl chloride (PVC) sewer pipe and fittings	ASTM D 2729
Polyvinyl chloride (PVC) pipe	ASTM D 3033 or D 3034 type PSM or PSP
Corrugated polyvinyl chloride tubing	SCS 606[c]
Corrugated polyethylene tubing and fittings	ASTM F 405
Corrugated polyethylene tubing and fittings, 8 to 15 inches	ASTM F 667
Pipe, corrugated (aluminum alloy)	WW-P-402[b]
Pipe, corrugated (iron or steel, zinc coated)	WW-P-405[b]

Source: Subsurface Drain (606) October 1980, Standards and Specifications, *Technical Guide,* Section IV, U.S. Department of Agriculture, Soil Conservation Service, Champaign, Illinois.
[a] ASTM specifications can be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.
[b] Federal specifications can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
[c] Specifications are given in the *Technical Guide.*

Clay drain tile

In ASTM standard specification C 4, clay drain tile is divided into three classes according to its physical test requirements: standard, extra-quality, and heavy-duty. Standard drain tile is satisfactory where the tiles are laid in trenches of moderate depth and width and where the tile will not be exposed to severe conditions. Use extra-quality and heavy-duty tile where conditions are expected to be severe. (Load requirements are discussed under the "Design" section.)

To be rated standard, clay drain tile that is 4 to 12 inches in diameter must have a crushing strength of 800 pounds or more per foot of length (Table 2). The tile must have an absorption rate not exceeding 13 percent for an average of five tiles. To be rated extra-quality, clay drain tile that is 4 to 14 inches in diameter must support at least 1,100 pounds per foot by the three-edge bearing test and have an absorption rate of not more than 11 percent. Heavy-duty tile has the same absorption rate as extra-quality tile but can support greater loads.

A few points to keep in mind about clay drain tile are that color and salt glazing are not reliable indicators of tile quality, that clay tiles are not affected by acids or sulfates, and that low temperatures normally will not damage clay tile, provided that it is properly selected for absorption and carefully handled and stored during freezing weather. To reduce chances for damage due to freezing, do not string out or stack clay tiles on wet ground during periods of freezing and thawing.

Table 2. ASTM Physical Test Requirements for Clay Drain Tile

Internal diameter, inches	Minimum crushing strength, lb/linear ft[a]		Maximum absorption, percent[b]	
	Average of five	Individual	Average of five	Individual
Standard				
4	800	680	13	16
5	800	680	13	16
6	800	680	13	16
8	800	680	13	16
10	800	680	13	16
12	800	680	13	16
14	840	720	13	16
15	870	740	13	16
16	...	...	13	16
Extra-quality				
4	1,100	990	11	13
5	1,100	990	11	13
6	1,100	990	11	13
8	1,100	990	11	13
10	1,100	990	11	13
12	1,100	990	11	13
14	1,100	990	11	13
15	1,150	1,030	11	13
16	1,200	1,080	11	13
Heavy-duty				
4	1,400	1,260	11	13
5	1,400	1,260	11	13
6	1,400	1,260	11	13
8	1,500	1,350	11	13
10	1,550	1,400	11	13
12	1,700	1,530	11	13
14	1,850	1,660	11	13
15	1,980	1,780	11	13
16	2,100	1,890	11	13

[a] Minimum crushing strength was determined by the three-edge bearing test. The number of freezing and thawing cycles for extra-quality and heavy-duty tile is 48 (ASTM designation C 4).
[b] Maximum water absorption was determined through 5 hours of boiling.

Concrete drain tile

Concrete drain tile of high quality will give long and satisfactory service under most field conditions. There are four classes of concrete drain tile:

1. ***Standard-quality*** tile is intended for land drainage of ordinary soils where the tiles are laid in trenches of moderate depth and width. Tile of this quality is not recommended where the internal diameter is more than 12 inches.
2. ***Extra-quality*** tile is intended for land drainage of ordinary soils where the tiles are laid in trenches of considerable depth, width, or both.
3. ***Heavy-duty, extra-quality*** tile is intended for land drainage of ordinary soils where the tiles are laid in trenches of relatively great depth, width, or both.
4. ***Special-quality*** tile is intended for land drainage where special precautions are necessary — for example, (a) where the tile is laid in soils that are markedly acidic (pH below 6.0) or that contain unusually high quantities of sulfates, or (b) where the tile is laid in trenches of considerable depth, width, or both.

ASTM standard specification C 412 lists the physical test requirements for each of these classes (Table 3).

Plastic drain tubing

High-density polyethylene (PE) is the most commonly used material for corrugated plastic drains in the United States. Polyvinyl chloride (PVC) is more commonly used in Europe. ASTM standard specification F 405 contains specifications for 3- to 6-inch corrugated polyethylene tubing (Table 4). ASTM standard specification F 667 includes specifications for tubing that is 8 to 15 inches in diameter. Standards are being developed for corrugated PVC tubing and fittings intended for systems involving soil drainage and wastewater.

Plastic tubing is not affected by acids and chemicals normally found in the soil at the drainage depth. Plastic may become stiff and brittle at very low temperatures or lose some of its stiffness when exposed to the sun on a hot day. But the sensitivity of plastic to temperature is a problem only while the tubing is being handled. Temperature ceases to be a problem once the tubing is installed and buried. If you install plastic tubing during unusually hot or cold weather, consult the manufacturer for advice on handling the tubing under those conditions.

Table 3. ASTM Physical Test Requirements for Concrete Drain Tile					
Nominal inside diameter, inches	Minimum crushing strength, lb/linear ft[a]		Maximum absorption, percent		Wall thickness, inches
	Average of five	Individual	Average of five	Individual	
Standard					
4	800	700	10	11	. . .
5	800	700	10	11	9/16
6	800	700	10	11	5/8
8	800	700	10	11	3/4
10	800	700	10	11	7/8
12	800	700	10	11	1
Extra-quality (Heavy-duty extra-quality)					
4	1,100 (1,300)[b]	990 (1,170)	9	10	1/2
5	1,100 (1,300)	990 (1,170)	9	10	9/16
6	1,100 (1,300)	990 (1,170)	9	10	5/8
8	1,100 (1,300)	990 (1,170)	9	10	3/4
10	1,100 (1,400)	990 (1,260)	9	10	7/8
12	1,100 (1,500)	990 (1,350)	9	10	1
14	1,100 (1,750)	990 (1,580)	9	10	1 1/8
15	1,100 (1,870)	990 (1,690)	9	10	1 1/4
16	1,100 (2,000)	990 (1,800)	9	10	1 3/8
18	1,200 (2,250)	1,080 (2,030)	9	10	1 1/2
20	1,330 (2,500)	1,200 (2,250)	9	10	1 5/8
22	1,460 (2,750)	1,320 (2,470)	9	10	1 3/4
24	1,600 (3,000)	1,440 (2,700)	9	10	2
Special-quality[c]					
4		1,100[d]	8	9	1/2
5		1,100	8	9	9/16
6		1,100	8	9	5/8
8		1,100	8	9	3/4
10		1,100	8	9	7/8
12		1,100	8	9	1
14		1,100	8	9	1 1/8
15		1,100	8	9	1 1/4
16		1,100	8	9	1 3/8
18		1,200	8	9	1 1/2
20		1,330	8	9	1 5/8
22		1,460	8	9	1 3/4
24		1,600	8	9	2

[a] Standard and extra-quality drain tile that meets these strength requirements is not necessarily safe against cracking in deep and wide trenches.
[b] The values in parentheses are the crushing strengths for heavy-duty, extra-quality tile.
[c] Where tile will be exposed to sulfates, use sulfate-resistant cement.
[d] For crushing strengths greater than or equal to those listed, use tile with increased wall thickness, stronger concrete, or reinforcing.

Design

The purpose of drainage is to lower the water table far enough below the ground surface that it will not interfere with plant root growth. The degree of drainage required depends upon the maximum allowable height of the water table, the minimum rate at which the water table must be lowered, or the maximum allowable duration and frequency of ponding. The designer of the subsurface drainage system should select the degree of drainage that will fit the various crop requirements of the site.

Drain size

One of the first steps in determining drain size is to select the drainage coefficient, which is the rate at which water is to be removed from an area. It is a value selected to provide adequate drainage for future crops and is expressed in inches per 24 hours (see Table 5).

Where field ditches or watercourses provide adequate surface drainage, the drainage area for which you are choosing a drainage coefficient need only include the area that will be drained by subsurface drains. If the slope of the field is less than 0.2 percent, choose the higher of the drainage coefficient ranges listed in the table.

Where surface drainage is not adequate and surface-water or blind inlets (see page 34) must be used to drain depressions, the drainage coefficient must be relatively high so that the drains can remove runoff from the entire watershed of the depressional area. An exception can be made where the depressions are small, as long as surveys are available and the volume of the potholes can be determined accurately. In that case, the drains should be able both to remove water at the appropriate drainage coefficient from the land area that needs drainage and to remove the water in the potholes within 24 to 48 hours.

The size of the drain depends not only upon the drainage coefficient, but also upon the size of the area to be drained, the grade of the drain, and the internal roughness of the pipe. The main should be large enough to drain all areas in the watershed that need drainage at the appropriate drainage coefficient. It should also have a free outlet and be deep enough to provide an outlet for all laterals to be installed.

To determine the size of plastic drains, refer to chart A in Figure 13; for clay and concrete tile, use chart B in the figure. First, find the appropriate drainage coefficient at the bottom right corner of the chart. In the column above the coefficient, find the acreage that will be drained by the subsurface drain. Next, locate the point at which a horizontal line through your acreage would intersect a vertical line through your drain grade or slope (horizontal axis). This point indicates the size of the drain and the velocity of water moving through it when it is flowing at capacity. The minimum cleaning velocity is 0.5 feet per second for drains not subject to the entry of fine sand or silt and 1.4 feet per second where fine sand or silt may enter. The rate of discharge information can be used in determining drain size at design slopes.

The smallest drain generally recommended for laterals is 4 inches. A drain 3 inches in diam-

Table 4. ASTM Physical Test Requirements for Corrugated-Plastic Tubing from 3 to 6 Inches

Physical property	Standard tubing	Heavy-duty tubing
Pipe stiffness at 5 percent deflection, psi	24	30
Pipe stiffness at 10 percent deflection, psi	19	25
Elongation, maximum percentage	10	5

Table 5. Drainage Coefficients for Subsurface Drains

Degree of surface drainage	Drainage coefficient, inches of water per day	
	Mineral soil	Organic soil
Field crops		
Good surface drainage	3/8 to 1/2	1/2 to 3/4
Blind inlets	1/2 to 3/4	3/4 to 1
Surface inlets	1/2 to 1	1 to 1 1/2
Truck crops		
Good surface drainage	1/2 to 3/4	3/4 to 1 1/2
Blind inlets	3/4 to 1	1 1/2 to 2
Surface inlets	1 to 1 1/2	2 to 4

A. Plastic tubing

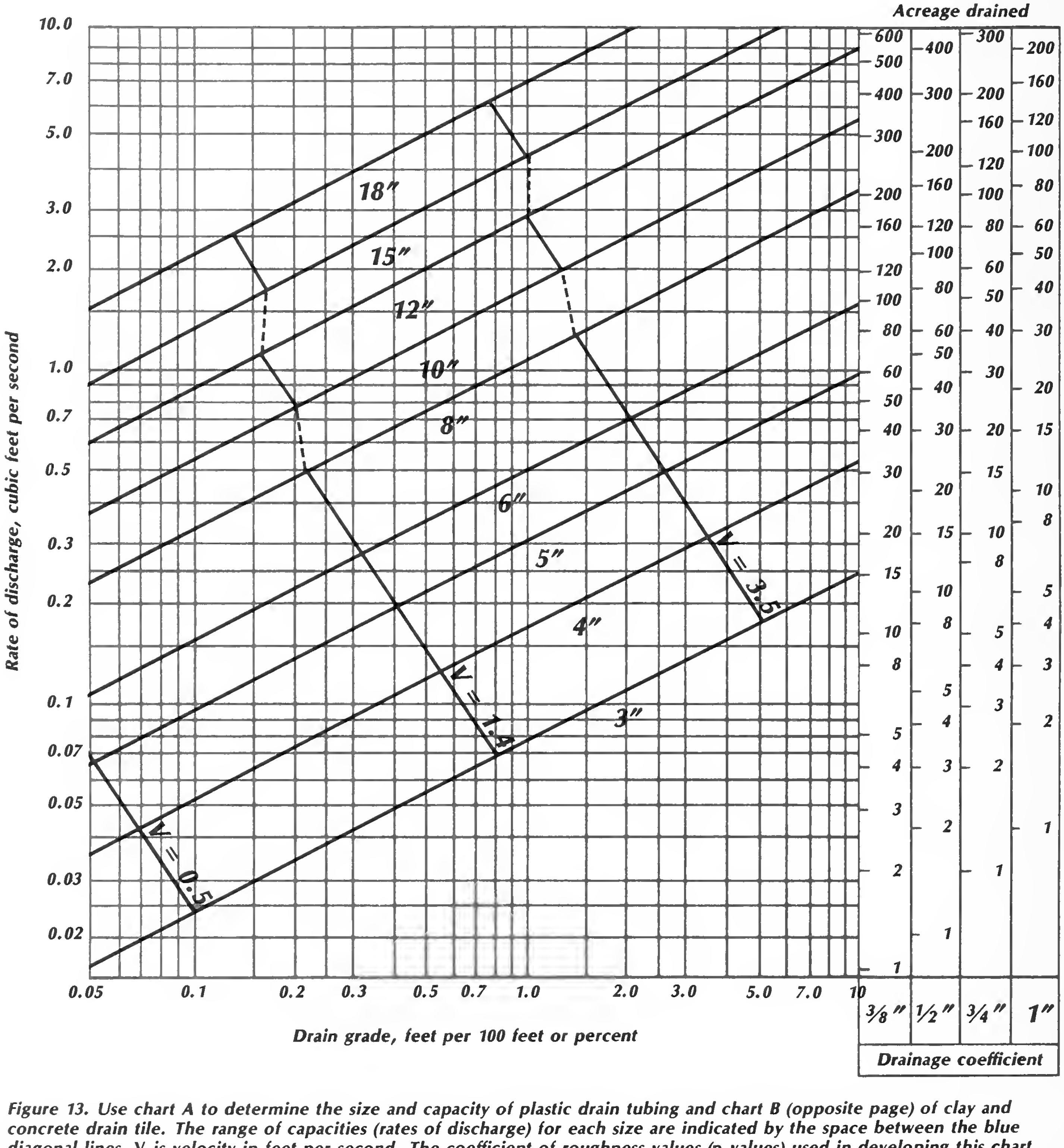
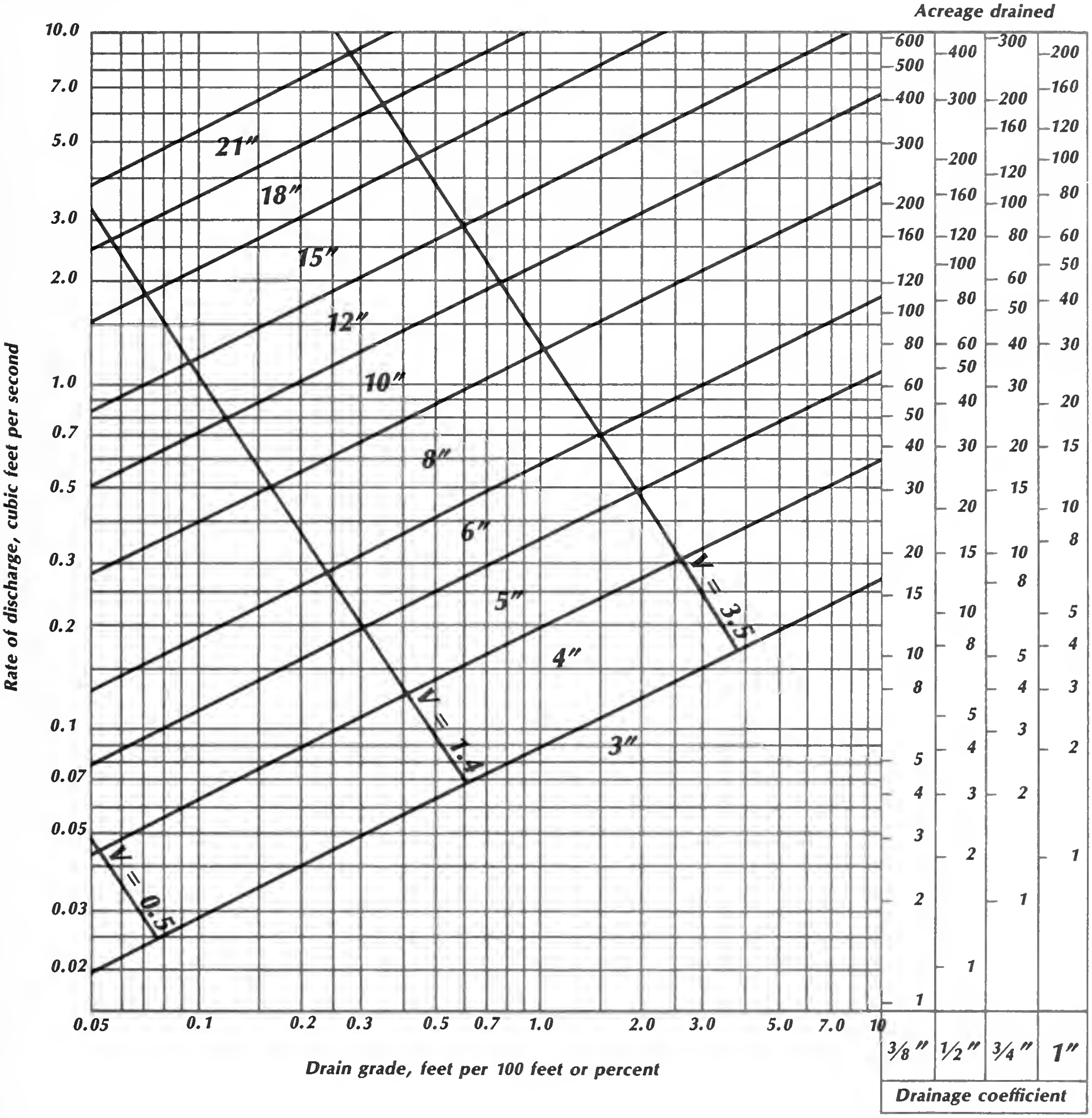


Figure 13. Use chart A to determine the size and capacity of plastic drain tubing and chart B (opposite page) of clay and concrete drain tile. The range of capacities (rates of discharge) for each size are indicated by the space between the blue diagonal lines. V is velocity in feet per second. The coefficient of roughness values (n values) used in developing this chart were 0.015 for 3- to 8-inch tubing, 0.017 for 10- to 12-inch tubing, 0.02 for tubing greater than 12 inches in diameter, and 0.013 for all sizes of clay or concrete tile.

B. Clay or concrete tile



eter may be installed in certain locations where the grade is 0.2 percent or more for clay and concrete tile and 0.3 percent for corrugated plastic tubing. The drain should be a minimum of 5 inches in diameter for a system with short laterals in sandy soils. Normally, 6 inches is the minimum diameter for drains located in organic soils and for main lines. For a subsurface system that contains tile lines exceeding 10 inches in diameter, it is preferable to use 2-foot or greater lengths to maintain alignment.

Drain length

The length of lateral drains made of corrugated plastic drain tubing and concrete and clay drain tile should not exceed the values given in Table 6, assuming that the drains are spaced 100 feet apart and that the drainage coefficient is ⅜ inch. To determine drain length for other drainage coefficients and lateral spacings, multiply the length listed in Table 6 by the appropriate adjustment factor listed below for different coefficients and spacing.

If coefficient is:	Factor is:
¼ inches	1.50
⅜	1.00
½	0.75
¾	0.50
1	0.38

If spacing is:	Factor is:
20 feet	5.00
30	3.33
40	2.50
50	2.00
60	1.67
66	1.52
70	1.43
80	1.25
100	1.00

Drain grade and velocity

When possible, subsurface drains should be placed at uniform depths. The range of grades on which they can be placed depends to some degree upon the topography of the land. The grade should be great enough to prevent silting but flat enough to prevent flow from exceeding the allowable velocity and subjecting the drain to excessive pressure. Too much flow would cause erosion around the drain. The grade should be as great as possible on flatlands. But you should not sacrifice adequate drain depth to increase the grade. The minimum grades of small drains are listed in Table 7.

Wherever the grades of drains are flatter than the minimum, take these precautions to reduce the amount of sediment:

- Make sure that the system has a free outlet so that backwater conditions will not further reduce velocity.
- Provide sediment traps and clean-out systems (see page 32).
- Provide breathers and relief wells (see pages 33 to 34) to vent the drain and to assure maximum flow.
- Protect the entire system from sedimentation by using filters and envelopes (pages 34 to 35) to prevent movement of the drain blinding materials.

For long laterals and main drains, the maximum velocity should be limited to those listed below, assuming that no protective measures are provided.

Soil texture	Velocity, ft/sec
Sand and sandy loam	3.5
Silt and silt loam	5.0
Silty clay loam	6.0
Clay and clay loam	7.0
Coarse sand or gravel	9.0

Table 6. Maximum Lengths of Corrugated Plastic Tubing and Clay and Concrete Drain Tile

Grade, percent	Drain diameter: 3 inches	4 inches	5 inches	6 inches
	(feet)			
Corrugated plastic tubing				
0.05	470	1,000	1,800	2,800
0.1	660	1,400	2,600	4,000
0.2	830	1,900	3,600	5,500
0.3	1,000	2,300	4,300	6,600
0.5	1,400	3,000	5,800	8,800
Clay and concrete tile				
0.05	520	1,160	2,100	3,450
0.1	750	1,650	3,000	4,900
0.2	830	2,200	4,100	6,900
0.3	1,100	2,700	5,000	8,300
0.5	1,660	3,600	6,600	10,800

Note: It is assumed that the drainage coefficient is ⅜ inch per day and that the spacing between drains is 100 feet.

Table 7. Minimum Grades of Small Drains

Inside diameter (inches)	Minimum grades for drains not subjected to fine sand or silt: Tile	Tubing	Minimum grades for drains where fine sand or silt may enter: Tile	Tubing
	(percent)			
3	0.08	0.10	0.60	0.81
4	0.05	0.07	0.41	0.55
5	0.04	0.05	0.30	0.41
6	0.03	0.04	0.24	0.32

Note: The minimum grades listed here were determined at full flow.

If protective measures do prove to be necessary, use one or more of the following.

For clay or concrete tile:

- Use tile uniform in size and shape with smooth ends.
- Lay the tile to secure a tight fit. The inside section of one tile should match that of the adjoining tile.
- Wrap open joints with tar-impregnated paper, burlap, or special filter material such as plastic sheets, fiberglass fabric, or properly graded sand and gravel.
- Select the least erodible soil for blinding.
- Tamp soil carefully under and alongside the tile before backfilling.
- Cement joints or use a drain with water-tight joints.

For corrugated plastic tubing or continuous pipe:

- Completely encase perforated drains with a filter material (see pages 34 to 35) made of plastic, fiberglass, or a like material, or use a properly graded sand and gravel filter.
- Use nonperforated corrugated plastic tubing or continuous pipe with taped or leak-proof connections.

Drain spacing and depth

The spacing and depth of drains influences the groundwater level between drains after a rain. Good drainage lowers the water table to at least 12 inches below the ground surface in the first 24 hours after a rain and to approximately 21 inches 48 hours after a rain. Incorrect spacing and depth could result in water remaining in the fields after 24 to 48 hours, significantly affecting crops (see Figure 14).

The spacing and depth required to keep the water table at the desired level are influenced by the permeability of the soil, depth to the barrier, the amount and frequency of rainfall, seepage, capillary movement, and topography. Spacing and depth also influence each other. In general, you should increase the lateral spacing the deeper you place the drain. Spacing and depth recommendations are given in the drainage guidelines (pages 4 to 8) for specific soils in Illinois. If your soil is not listed in the guidelines, keep in mind the following general principles about drain spacing and depth.

Drains in rapidly permeable soils should be spaced 200 to 300 feet apart, while those in moderately rapidly permeable soils should be spaced 100 to 200 feet apart. Where soil permeability is moderate, spacing should be 80 to 100 feet apart. In slowly permeable or moderately slowly permeable soils, drains should be spaced 30 to 70 feet apart or 60 to 80 feet apart, respectively.

With respect to general principles for depth, drains in moderate to moderately permeable mineral soils in humid areas should be installed at a depth of 3 to 5 feet. At this depth the drains will lower the water table to not less than 2 to 4 feet. Because the upward capillary action is limited in very sandy soils, the drains should be no deeper than 4 feet. In slowly permeable clay soils, the rate of lateral water movement does not increase with depth. Therefore, the drain is usually placed approximately 1 foot below the desired water table.

The depth of drains also depends upon conditions other than those mentioned above — the depth of frost penetration, for example. If possible, place drains below the frost line to obtain optimum year-round drainage and

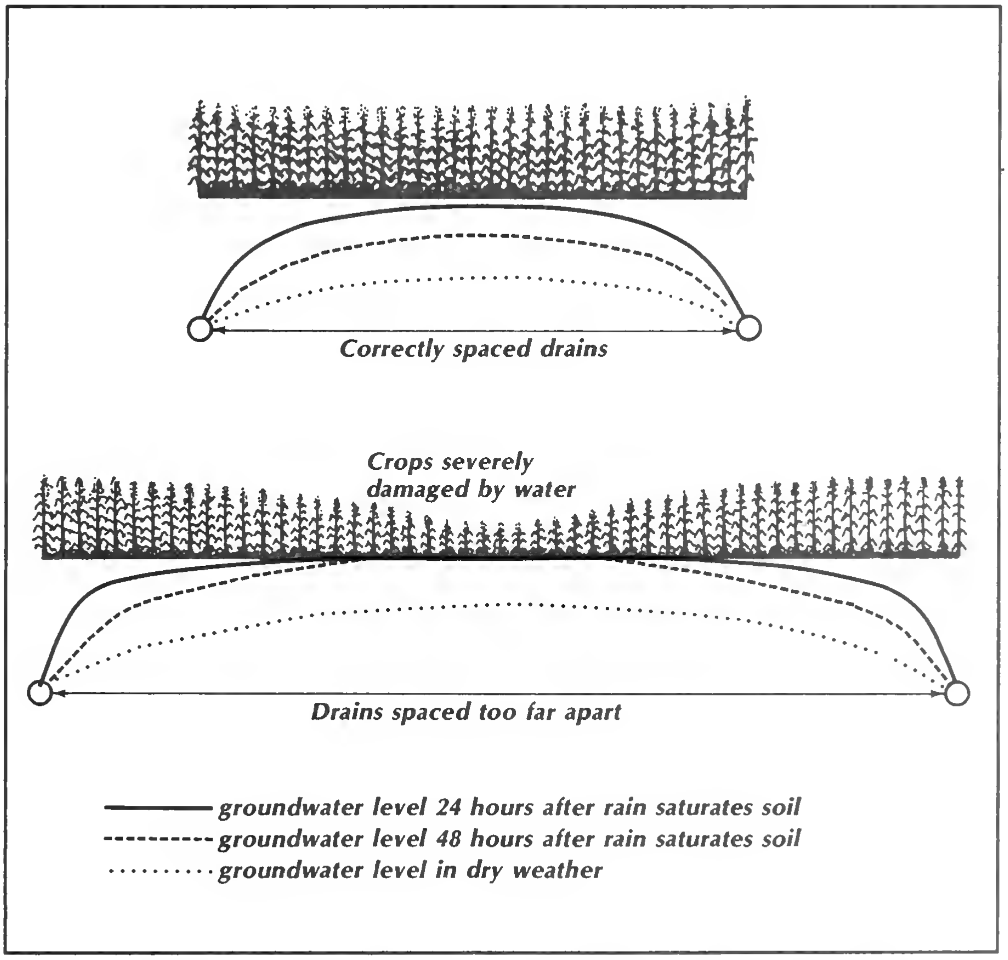


Figure 14. The effect of drain spacing upon groundwater level and crop damage.

to prevent damage to the line. Figure 15 shows the average annual depth of frost penetration for the state of Illinois.

To protect a well-bedded subsurface drain in a mineral soil from breakage or excess deflection of flexible tubing by heavy equipment, make sure that the drain has a minimum coverage of 2 feet. Where 3-inch drains are used both for drainage and subirrigation of shallow-rooted crops, the minimum depth may be 1.5 feet if heavy machinery is not used in the cropped area. The minimum depth of cover in organic soils should be 2.5 feet for normal field levels after initial subsidence. If controlled drainage is not provided to hold subsidence to a minimum, the depth of cover should be increased to 3 feet. The outlet should be deep enough for the lateral drain to have adequate grade and cover. When it is impossible to provide minimum cover for protection, use metal or some other continuous high-strength pipe.

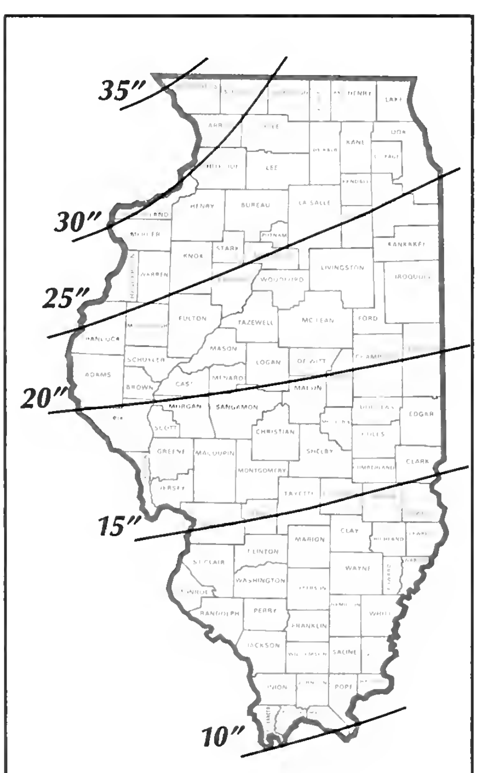


Figure 15. The average annual depth of frost penetration.

Table 8. Percentage of Wheel Loads Transmitted to Underground Drains

Backfill depth over top of drain, feet	Trench width at top of drain						
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet
				(percent)			
1	17.0[a]	26.0	28.6	29.7	29.9	30.2	30.3
2	8.3	14.2	18.3	20.7	21.8	22.7	23.0
3	4.3	8.3	11.3	13.5	14.8	15.8	16.7
4	2.5	5.2	7.2	9.0	10.3	11.5	12.3
5	1.7	3.3	5.0	6.3	7.3	8.3	9.0
6[b]	1.0	2.3	3.7	4.7	5.5	6.2	7.0

[a] These percentages include both live load and impact transmitted to 1 lineal foot of drain.
[b] Live loads transmitted are practically negligible below 6 feet.

Table 9. Maximum Trench Depth for Tubing Buried in Loose, Fine-Textured Soil

Nominal diameter of tubing, inches	Quality of tubing	Trench width at top of tubing			
		12 inches	16 inches	24 inches	32 inches
			(feet)		
4	Standard	12.8	6.9	5.6	5.2
	Heavy-duty	...[a]	9.8	6.9	6.2
6	Standard	10.2	6.9	5.6	5.2
	Heavy-duty	...[a]	9.5	6.6	6.2
8	Standard	10.2	7.2	5.6	5.2
	Heavy-duty	...[a]	9.8	6.9	6.2
10		...	9.2	6.6	6.2
12		...	8.9	6.6	6.2
15		...	...	6.9	6.2

Source: Adapted from Fenemor, A. D., B. R. Bevier, and G. O. Schwab. 1979. Prediction of deflection for corrugated plastic tubing. *Transactions of the ASAE* 22(6): 1338-1342.
[a] Tubing of this diameter or less and of this quality can be buried at any depth.

Live loads should be added to soil loads in the determination of depth. Table 8 shows the percentage of wheel loads transmitted to the drain. After determining load requirements, select the class of tile or tubing that will meet the requirements.

Plastic drain tubing should be installed in such a way that it does not deflect more than 20 percent of its inside diameter. The maximum trench depths for tubing that is buried in loose, fine-textured soils are listed in Table 9. Because the maximum depths listed in the table are based on a limited amount of research, they should be used with caution. Keep in mind, too, that these values are based on certain assumptions about corrugation design and pipe stiffness (which may not be the same for all commercial tubing) and about soil conditions. Because of variation in these characteristics, you may need to increase or decrease the maximum depths listed in Table 9.

The maximum allowable trench depths for drain tile are listed in Table 10.

Table 10. Maximum Allowable Trench Depths for Drain Tile									
Crushing strength, lb/linear ft[a]	Tile diameter, inches	Trench width at top of tile							
		18 in.	21 in.	24 in.	27 in.	30 in.	36 in.	42 in.	48 in.
					(feet)				
800	4, 5, 6	9	7	7	7	7	7	7	7
800	8	9	7	6	6	6	6	6	6
800	10	10	7	6	5	5	5	5	5
800	12	...	7	6	5	5	5	5	5
840	14	...	...	6	5	5	5	5	5
870	15	...	...	6	5	5	5	5	5
1,000	6	19	9	8	8	8	8	8	8
1,000	8	19	9	7	7	7	7	7	7
1,100	4, 5, 6	25+	11	9	9	9	9	9	9
1,100	8	25+	11	8	7	7	7	7	7
1,100	10	25+	11	8	7	6	6	6	6
1,100	12	...	11	8	7	6	6	6	6
1,100	15	...	...	8	7	5	5	5	5
1,150	15	...	...	9	7	6	5	5	5
1,200	12	...	14	9	7	6	6	6	6
1,200	16	...	...	10	8	7	5	5	5
1,200	18	...	...	...	8	7	5	5	5
1,250	4, 5, 6	25+	16	11	11	11	11	11	11
1,300	4, 5, 6	25+	18	11	11	11	11	11	11
1,300	8	25+	18	11	8	8	8	8	8
1,300	18	...	...	...	9	7	5	5	5
1,350	8	25+	22	11	9	9	9	9	9
1,400	4, 5, 6	25+	25+	12	10	10	10	10	10
1,400	10	25+	25+	12	9	8	8	8	8
1,400	15	...	...	13	9	8	6	6	6
1,450	4, 5, 6	25+	25+	13	11	11	11	11	11
1,500	8	25+	25+	14	10	9	9	9	9
1,500	12	...	...	14	10	8	7	7	7
1,550	10	25+	25+	15	11	9	8	8	8
1,600	4, 5, 6	25+	25+	16	12	12	12	12	12
1,600	8	25+	25+	16	11	10	10	10	10
1,600	10	25+	25+	17	11	9	9	9	9
1,600	14	...	...	17	12	8	7	7	7
1,650	15	...	...	19	12	10	7	7	7
1,700	8	25+	25+	25	12	11	11	11	11
1,700	12	...	...	25	12	10	8	8	8
1,700	16	...	...	25	13	11	8	7	7
1,700	18	...	...	...	13	11	8	7	7
1,750	15	...	...	25	14	11	8	7	7
1,800	8	25+	25+	25+	14	11	8	8	8
1,800	12	...	...	25+	15	11	8	7	7
1,800	18	...	...	...	15	11	8	7	7
1,850	14	...	...	...	15	11	8	8	8
2,000	4, 5, 6	25+	25+	25+	19	14	14	14	14
2,000	8	25+	25+	25+	19	12	12	12	12
2,000	10	...	25+	25+	19	13	10	10	10
2,000	18	...	...	...	20	14	9	7	7

Note: In the calculation of trench depth, soil weight was assumed to be 120 pounds per cubic foot and the safety factor to be 1.5.
[a] Crushing strength was tested by the three-edge-bearing test.

To prevent overloading in deep and wide ditches, you may want to construct a subditch, either with a trenching machine or by hand, in the bottom of a wide ditch that has been excavated by a bulldozer, dragline, power shovel, or backhoe. It is now the width of the subditch measured at the top of the drain that influences the allowable load; the width of the excavation above that point is relatively not important. It is a good idea to backfill deep trenches in several stages to allow time for settlement between fillings.

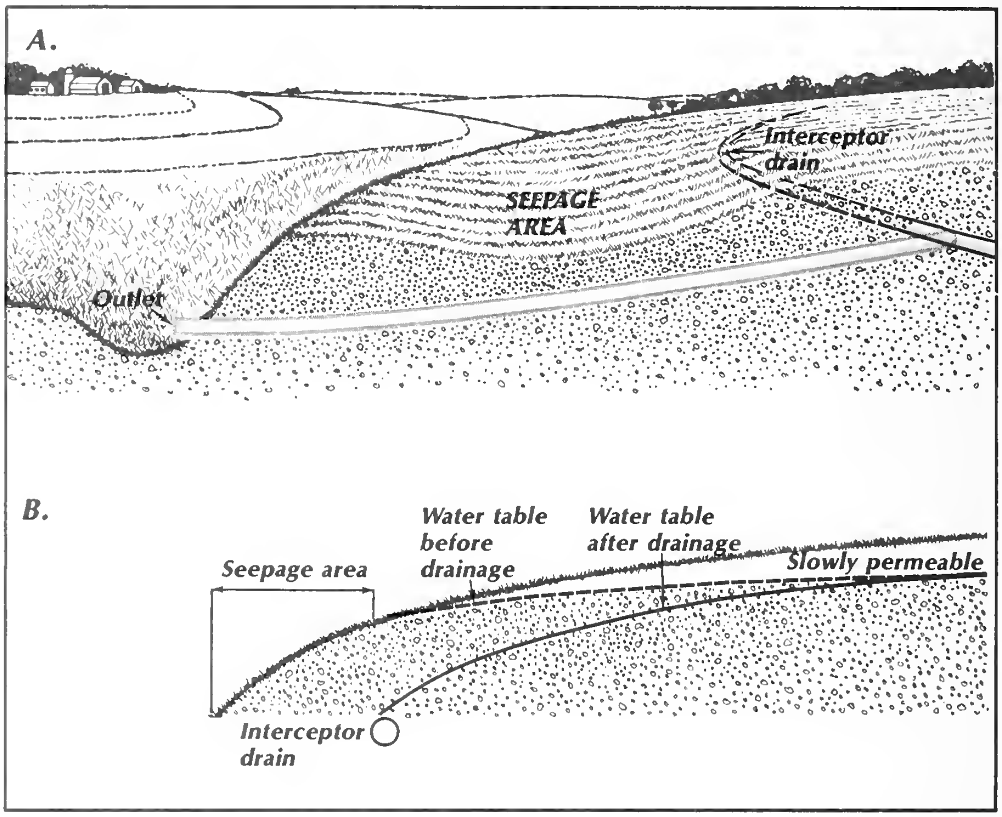


Figure 16. Drawing A shows an interceptor drain installed at the upstream boundary of a seepage area. Drawing B is a side view showing how an interceptor drain lowers the water table above an impervious area and usually eliminates the seepage area.

Interceptor drains

An interceptor drain can be used in areas that are wet because of seepage from adjoining highlands. The drain is also used to intercept seepage or water that flows in a pervious layer on top of an impervious subsoil stratum.

Proper location of an interceptor drain is very important. An interceptor drain is usually buried at about the upstream boundary of the wet area. The drain is installed at approximate right angles to the flow of groundwater and intercepts a seep plane in the soil profile (Figure 16). Adequate field investigations must be made to determine the amount of seepage and to identify seep planes. You can locate seep planes by making backhoe test pits or taking soil borings.

An interceptor drain must intercept the seep plane continuously, have adequate soil coverage, and be on a continuous grade toward the outlet. The drain is usually located one-half to one times its diameter deep in the impervious layer or seepage plane.

One or two properly spaced interceptor drains will usually dry up a wet area. The flow will often be continuous throughout much of the year. In a steeply graded depression or draw, the layout may consist of a main or submain located in the draw or to one side of it and interceptor lines located across the slope on grades slightly off contour.

To determine the size of an interceptor drain for a particular set of conditions, refer to the list below, which contains inflow rates for various soil textures. Measure or estimate the discharge of flowing springs and the direct entry of any surface flow through a surface inlet or filter. Add that figure to the rate of inflow. If the interceptor lines are being installed on sloping land, increase the inflow rate by 10 percent for slopes of 2 to 5 percent, by 20 percent for slopes of 5 to 12 percent, and by 30 percent for slopes of more than 12 percent. Once you have determined the inflow rate, you can then determine the drain size, using Figure 13. For interception areas where there is considerable seepage, the minimum drain size should be 6 inches.

Soil texture	**Inflow rate, per 1,000 ft of line cu ft/sec**
Coarse sand and gravel	0.15 to 1.00
Sandy loam	0.07 to 0.25
Silt loam	0.04 to 0.10
Clay and clay loam	0.02 to 0.20

Changing the direction of drains

You can change the horizontal direction of drain lines by several means. Curve the trench gradually on a radius of curvature that the trenching machine can dig while still maintaining grade. The joint spacings for tile should be no more than $\frac{1}{16}$ to $\frac{1}{8}$ inch. Use manufactured bends or fittings, or use junction boxes where drain lines make an abrupt change in direction or where two or more large drains join.

Special components

Outlet pipes

To protect drains from erosion and undermining, install outlet pipes on the end of all drains that outlet into an open ditch.

Assuming that no surface water enters the ditch at the drain outlet, the most practical and economical protection is a length of continuous pipe that does not have perforations or open joints. The pipe should be long enough (a minimum of 8 feet) to ensure that no seepage will occur around the drain and cause erosion at the outlet. At least two-thirds of the pipe should be embedded in the bank to provide the required cantilever support. The flow line of the outlet pipe should be at least 1 foot above the normal water surface in the outlet ditch (Figure 4). A pipe projecting into the ditch can either be damaged or destroyed by floating ice and debris or cause a serious ice jam. Where this possibility exists, the pipe should be recessed into the ditch bank (as shown in Figure 17) and protected with riprap. Where there is not enough soil cover at the outlet, use one of the methods shown in Figure 18 to protect the drain.

Where surface water does enter the ditch at the drain outlet, some type of structure should be installed to lower the surface flow safely to the ditch (Figure 19). If

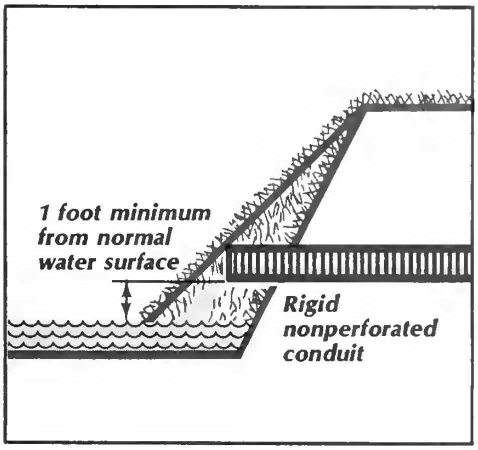


Figure 17. Recessed outlet pipe.

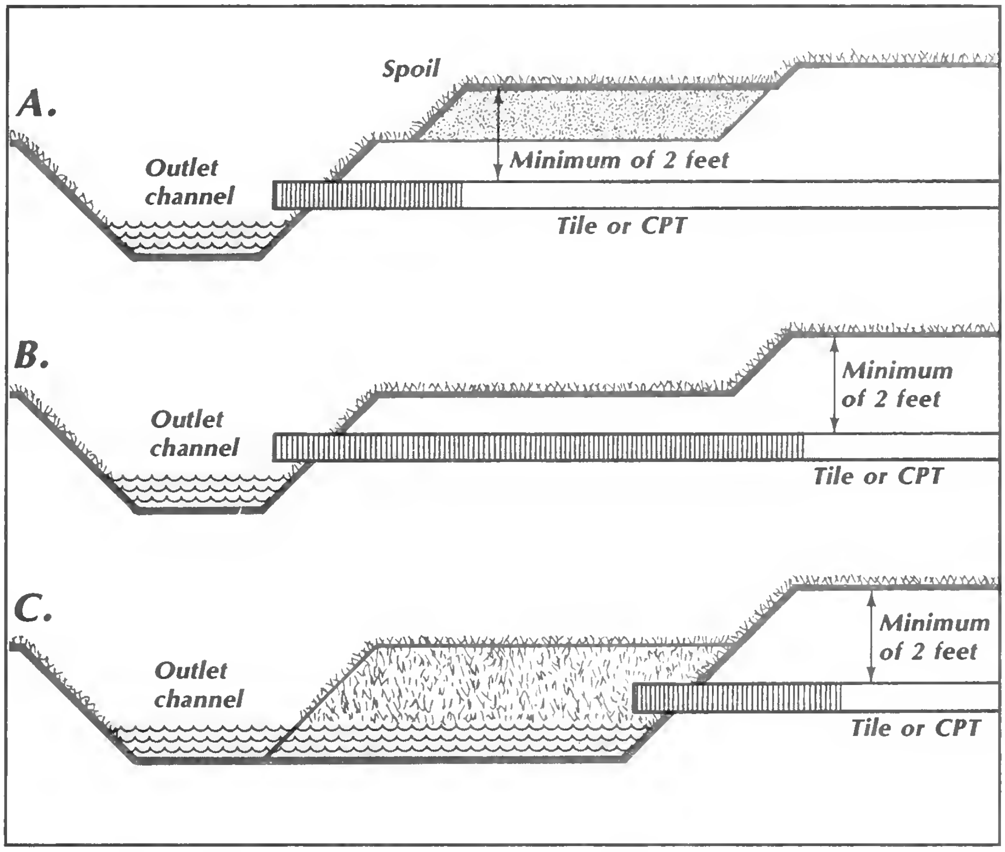


Figure 18. These drawings show three methods for protecting drain outlets where there is not enough soil cover (less than 2 feet). In drawing A, fill is placed over the drain to provide the minimum soil cover; in B, a metal pipe is extended through the section where soil cover over the drain is less than 2 feet; and in C, a ditch is excavated back to where the cover over the drain is more than 2 feet.

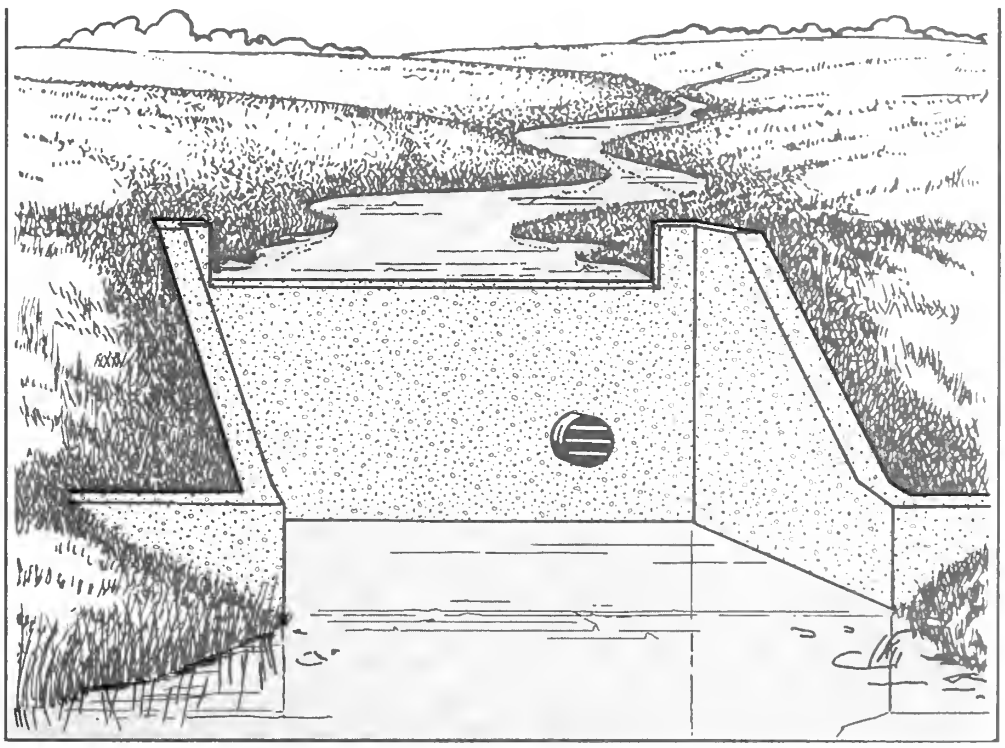


Figure 19. Straight drop spillway used to protect subsurface drain entering channel.

there is no spoil bank, a straight-drop spillway is generally the best type of structure. But if there is a spoil bank and enough temporary storage for surface water, it is usually more economical to install a pipe drop-inlet. Sometimes you can move the drain outlet out of the waterway or divert the surface water to another location at least 60 to 75 feet away and lower the surface flow into the ditch over a sodded chute.

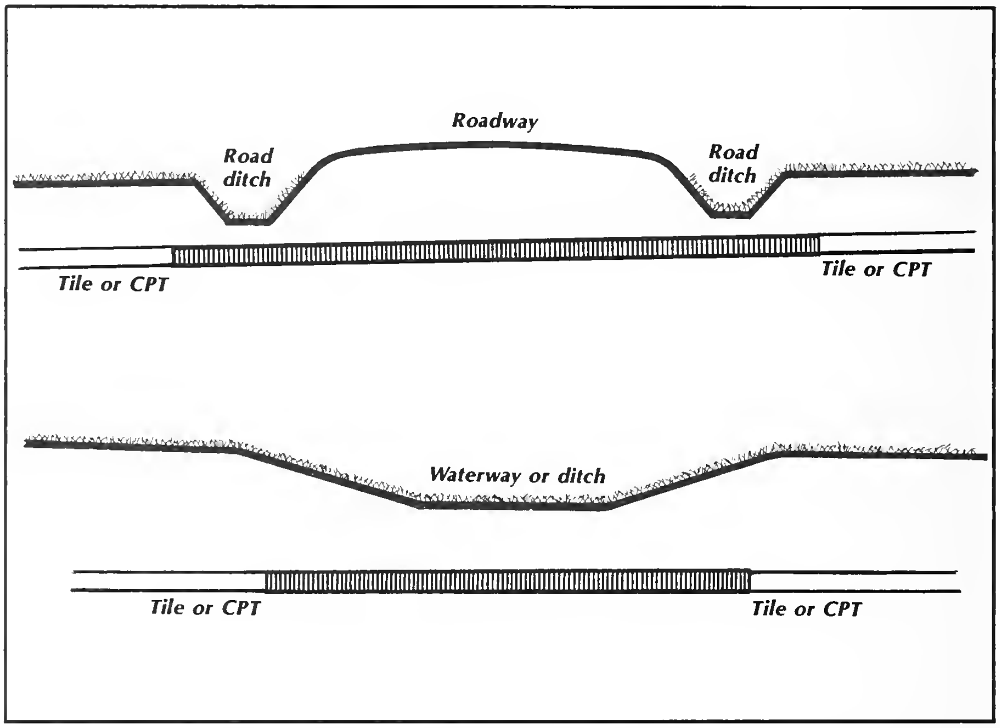


Figure 21. Drains that cross under roads, waterways, or ditches should be constructed of metal pipe, extra-strength sewer tile with cemented joints, or drain tile encased in 4 inches of concrete.

Animal guards

Animal guards such as rods, flap gates, and finger-type flap gates should be used on the outlets of all drains that are accessible to small animals (Figure 20). Fixed pins are suitable for lines that do not have surface-water inlets. Insert the pins horizontally through the end of the outlet pipe, not more than 1½ inches apart. Check the outlet frequently to be sure that roots and other debris carried through the drain do not block the openings between pins.

Fixed pin guards are not suitable for lines that do have surface-water inlets because the guards can easily become plugged up by the small material that continually washes through them. For those lines, use flap gates made of noncorrosive material.

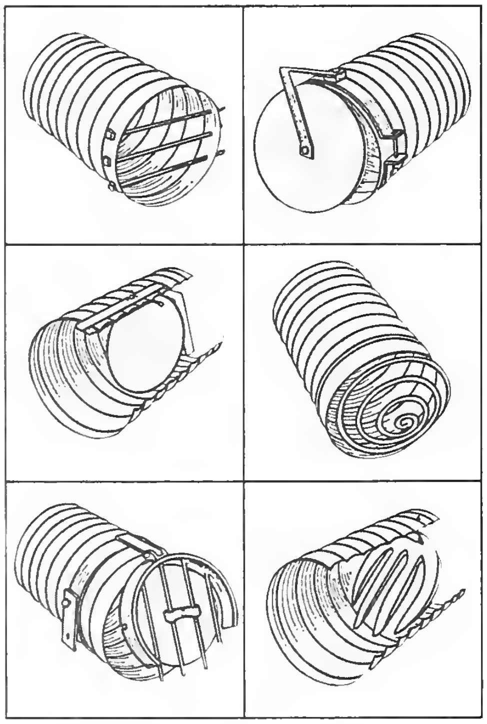


Figure 20. Animal guards.

Drain crossings

Where subsurface drains cross under waterways or other ditches, the conduits should be watertight and strong enough to withstand the loads put on them. Design conduits that pass under roadways to withstand the expected loads and meet the requirements of the appropriate railroad or highway authority (Figure 21). (Tables 9 and 10 list the maximum allowable trench depths for tile and tubing, and Table 8 gives the percentages of wheel loads transmitted to underground drain.) Be sure to obtain written permission to construct drains under roads from the responsible road official. Protect shallow drains in depressional areas and near outlets against damage by farm and other equipment and by freezing and thawing.

Junction boxes and sediment traps

Junction boxes are used where two or more drains join at different elevations or where a drain changes direction abruptly. They can also serve as sediment traps, which are placed downstream from surface-water inlets to catch sediment and trash entering the line. Locate junction boxes in permanent fence rows or in noncultivated areas. Be sure that the capacity of the outlet drain equals the combined capacity of the incoming drain lines and that the elevation of the outlet drain's flow line is at the same level or below the flow line of the lowest incoming drain (Figure 22). Place the junction box cover aboveground to provide easy access for inspection. In cultivated fields, the top of the box should be at least 18 inches below the ground surface.

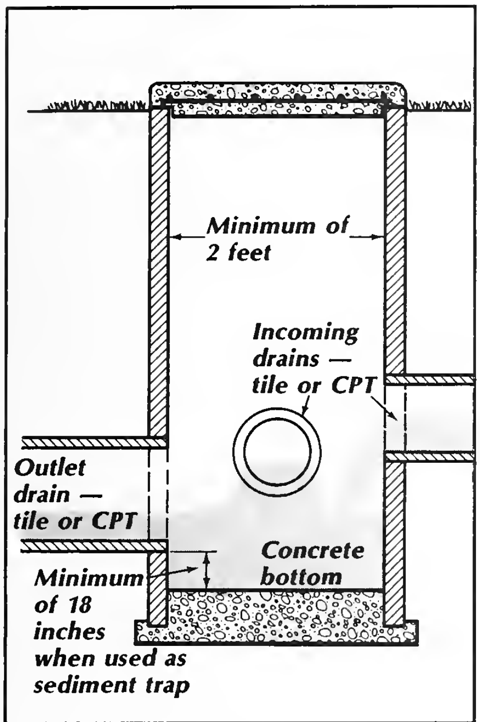


Figure 22. Junction boxes and sediment traps should be constructed of materials that have adequate strength and durability to carry the applied loads.

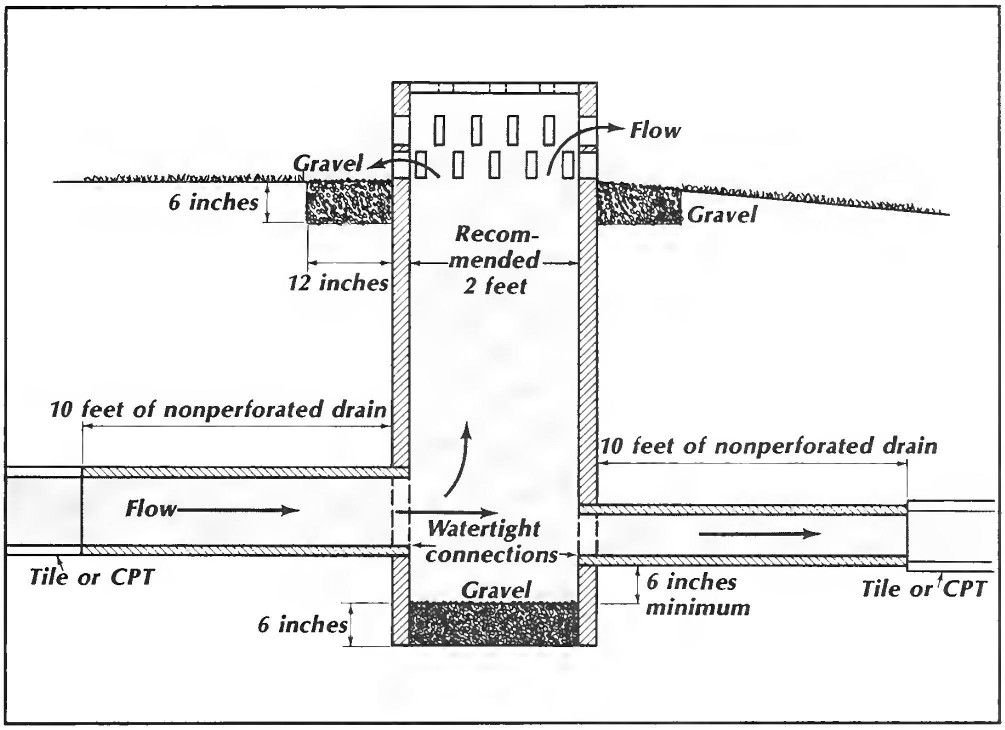


Figure 23. Relief wells relieve pressure in drain lines. They are typically used where tile outlet terrace systems connect to drainage mains.

Pressure relief wells

A well relieves pressure in drain lines that might otherwise cause them to blow out. A relief well can be constructed by placing a T connection in the line and fitting a riser vertically into the T (Figure 23). The riser should outlet at the ground surface; the exposed end should be covered with heavy wire mesh or grating. The size of the riser should be equal to or greater than the diameter of the line. Locate relief wells where the drain line might become overloaded for short periods. This is more apt to occur where there is a change from a steeper to a flatter grade and where there are surface inlets.

Pressure relief wells that are intended to function frequently (as with underground outlets that carry surface water from terraces or other temporary impoundments) should be designed to keep the hydraulic gradeline as low as possible, preferably below the ground line. This may best be achieved by outletting near the gradeline of a grassed waterway or surface drain.

Connections

Manufactured connections should be used for joining two tile lines at a junction. If connections are not available, the junction should be chipped, fitted, and sealed with cement mortar.

For drainage systems constructed of corrugated plastic tubing, use manufactured fittings at all joints, at all changes in direction where the radius of the centerline is less than three times the diameter of the tubing, at changes in diameter, and at the end of the line. All connections must be compatible with the tubing. If certain fittings are not available, hand-cut holes are acceptable, provided that they are reinforced with cement mortar or other material that will make the joint tight. When making the connection, be careful not to create a means of obstructing flow or catching debris inside the conduit or allowing soil to enter the line.

Mains should be laid deep enough to permit the centerlines of the laterals to be joined at or above the centerline of the main.

Breathers or vents

Breathers, sometimes referred to as vents, can be constructed as shown in Figure 24. They allow air to enter the drain for the purpose of venting the line. Breathers are usually installed where the line is longer than ¼ mile or where the line changes from a flat to a steep grade and full flow occurs in the line with the flat grade.

Exposed material needs to have resistance to ultraviolet light and fire. The riser should be 4 inches in diameter for 15-inch and smaller drain lines and 6 inches

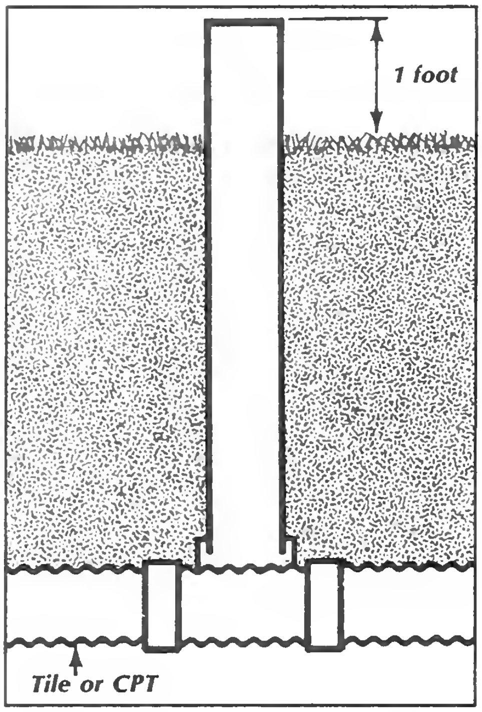


Figure 24. Breathers or vents allow air to enter drain line.

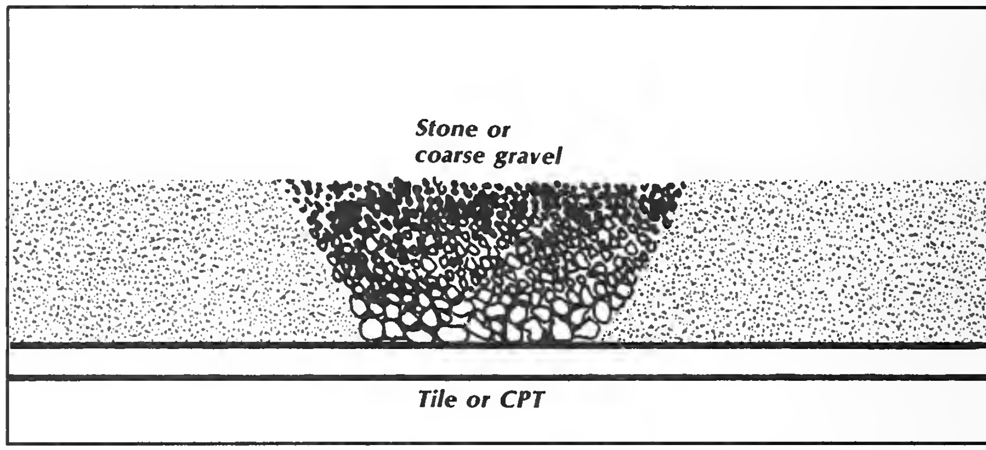


Figure 25. Blind inlets remove both surface and subsurface water and are suitable where there are relatively small amounts of impounded water.

for drain lines that are 18 inches or larger. Cover the top of the riser with a heavy wire-mesh screen or some type of perforated cap.

Blind inlets

Blind inlets remove both surface and subsurface water. They are most useful in open fields because they do not hinder farming operations. Since blind inlets remove impounded water at a much lower rate than surface-water inlets, the former should not be used where there is a large amount of impounded water.

Described below is one method of constructing a blind inlet. Fill a section of the trench around and up to about 6 inches above the drain with stone, gravel, crushed rock, or a combination of these materials (see the section on envelopes, page 35). Grade the material upward from coarse to fine to within approximately 12 inches of the ground surface and cover the material with topsoil. To increase the intake of water, especially in areas where silting is a problem, use pea gravel, small stones, or coarse sand instead of topsoil (Figure 25). You can also construct the blind inlet of graded gravel. The length of time for which the blind inlet will be useful depends upon the care with which it is installed, the fill material, and the amount of sediment that reaches the inlet.

Surface-water inlets

Surface-water inlets allow surface water to enter subsurface drains (Figure 26). Because of the high cost of carrying surface water in buried drains, inlets are recommended only for draining low areas where it is not feasible to install a surface drainage system. If you have to use surface-water inlets, place nonperforated tubing or conduit on each side of the riser. Since surface-water inlets may be a source of weakness in a drainage system, you might consider offsetting the inlet to one side of the line to reduce the hazard to the main line (Figure 27).

Surface-water inlets not projecting above the surface should be protected with a cone grate (often referred to as a "beehive"). The cone grate tends to float flood debris, preventing it from closing off the entrance.

Metal pipes and other durable materials with holes or slots may be used as inlets. Flow control devices may be necessary to limit the amount of water entering the drain. One way of limiting water flow is to install an orifice plate near the bottom of the inlet. Where it is likely that a substantial amount of sediment will enter the surface-water inlet, it is advisable to construct a sediment trap.

Filters and envelopes

The need for a filter or envelope depends upon the characteristics of the soil material at drain depth and the velocity of flow in the conduit. Filters may be required in sand, silt, and some organic soils to prevent sediment from accumulating in the drain. A filter is required where the base material is uniform, fine to medium sand and where flow reaches such high velocities that it moves the sand into the drain.

Filters may be sand and gravel envelopes or manufactured filter material. Most of the presently available, artificial, prefabricated filter materials, such as fiberglass, spun-bonded or knitted synthetic fabrics, and plastic filter cloth, act as protective filters. With time,

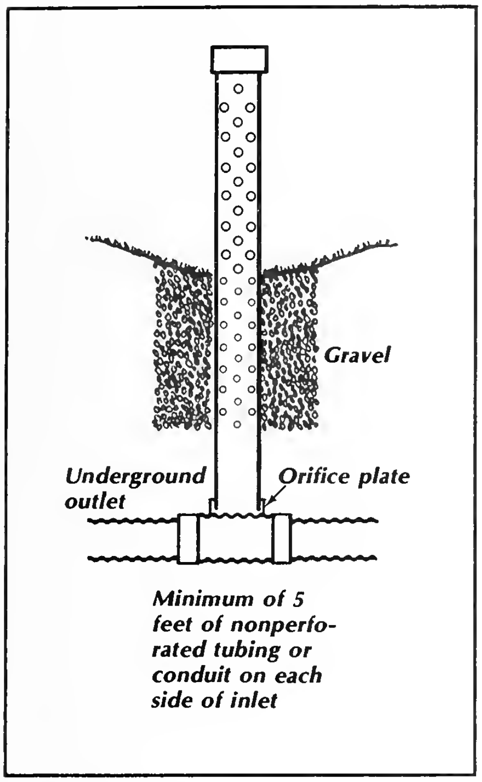


Figure 26. A surface-water inlet connected directly to a subsurface drain line. Typically the length of the riser is 5 feet.

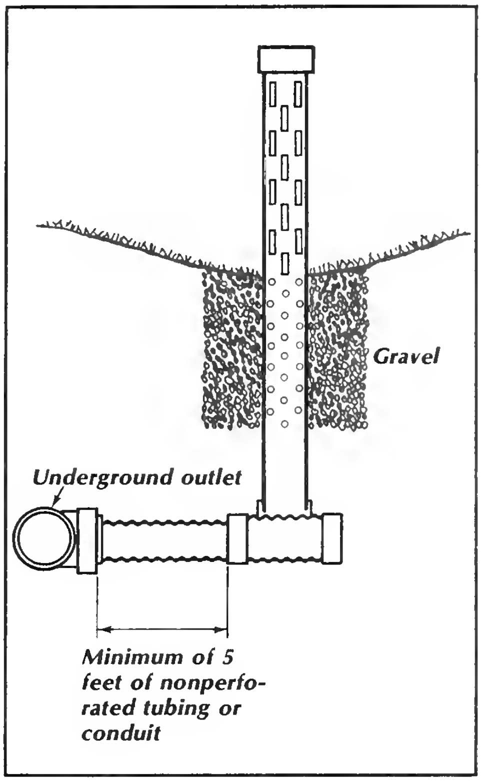


Figure 27. A surface-water inlet offset from the subsurface drain line to reduce potential damage to the line.

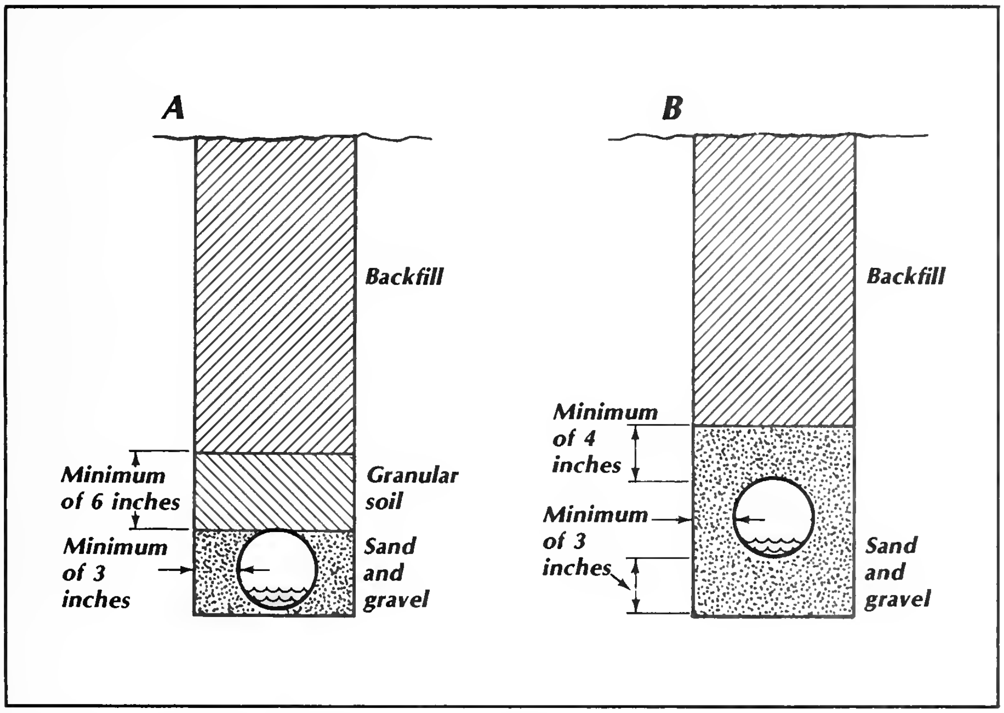


Figure 28. Two ways of placing envelope materials around drains. In drawing A the sand and gravel envelope supports the drain; in B the envelope acts as a filter. If fine particles are present in the soil, the envelope should be designed as in drawing B.

however, these materials may partially clog and decrease flow into the drain. Manufactured filters should have openings of sufficient size and enough strength, durability, and permeability to provide constant filtering of the soil material and to protect the drain throughout the expected life of the system. Make sure that the manufacturer of the material has certified it for underground use. During installation the material should span all open joints and perforations without being stretched excessively. Be careful not to damage the material during installation. Any damaged areas should be replaced before backfilling.

Installing envelope material around subsurface drains provides them proper bedding support and improves the flow of groundwater into the drain. Where it is not feasible to form a bedding groove for plastic drain tubing, envelope material can be substituted for bedding. The minimum thickness of the envelope may vary from 3 to 6 inches, depending on the type of equipment used to install the material and the availability of the gravel material. For all envelope designs, if the trench is wider than the specified width of the envelope, the trench must be filled on both sides with bedding material or a gravel envelope so that no space is left between the drain and the walls of the trench.

Figure 28 shows various ways of placing envelope materials around drains. Although gravel envelopes are not normally designed to be filters, they do act as partial filters because their gradation is better than that of the base material.

Preinstallation considerations

In order for a subsurface drainage system to perform properly, it must be installed correctly. Assuming that the system is well designed and constructed of high-quality materials, proper installation will greatly reduce maintenance and prolong the life of the system. Recommended installation techniques are provided for 3- to 8-inch corrugated polyethylene tubing in ASTM installation standard F 449, which is currently being revised to include specifications for larger sizes.

Plans and records

Ideally, all construction should follow a definite plan that has been prepared in advance by the designer of the system specifically for the drainage contractor. The plan should include profiles and construction notes for all mains and submains and a map showing the locations, sizes, and grades of all lines and other components of the system. The map also should show physical features so that components of the system can be readily located in the future for repairs and maintenance. The location of buried cables, pipelines, or other utilities also should be noted (long before construction begins, the owner should obtain any necessary permission or easements that might be required to cross the land of private owners, highways, railroads, etc.).

The contractor should carefully examine the plan before work is begun and should not proceed with installation until the public utilities have marked the exact location of any buried obstacles at points where drains are to be constructed. As the work proceeds, the contractor should be careful to note on the plan and map any modifications in the design that are necessitated in the field, especially any changes in grade. Once the job is completed, the contractor should give the landowner the plan and map showing the system exactly as it was installed in the field. We recommend that the owner file one copy of the plan with the legal papers for the land and keep a working copy with the farm records.

If a drainage system is designed in the field, the designer, with the help of the contractor, should prepare a final, as-constructed plan with notes for the landowner.

Inspection of materials

The contractor should inspect construction materials before and during installation. All materials should be satisfactory for the intended use and should meet the requirements described in the section of this publication on quality of materials (page 20) and any additional requirements of the owner. Reject any defective or damaged clay or concrete drain tile; remove defective or damaged sections of plastic tubing. Make sure that the perforations in the plastic tubing are of the proper size.

Storage of materials

Drainage materials should be protected from damage during handling and storage. The storage area should be dry, well drained, and free of rodents, vegetation, and fire hazards. It should have a protected floor (peagravel or cement) and adequate security.

Take more precautions to protect plastic tubing. Where rodents could be a problem, we recommend that you use end caps. Tubing with filter wrap should either be stored inside or placed in protective bags. Since tubing can be harmed by excessive exposure to ultraviolet rays, protect it from sunlight when it is to be stored outside for a long period. To protect coils or reels of tubing from damage and deformation, lay them flat when they are stored for extended periods. Coils of tubing should be stacked no more than four high; reels should not be stacked.

Tree removal

Before installation begins, remember to remove willow, elm, soft maples, cottonwood, and other water-loving trees that grow within approximately 100 feet of the planned drainage lines. All other species of trees, with the possible exception of fruit trees, should be removed for a distance of 50 feet. If it is not possible to remove trees or to reroute the line, use a nonperforated line with sealed joints throughout the root zone of the tree or trees.

Grade control

All drains should be installed at a predetermined grade that will give them the capacity required for the area to be drained. This grade should be maintained constantly during installation. The easiest way to control the grade is to use equipment that is designed especially for drainage installation. If you use a backhoe or other equipment, you must take extra precautions to ensure that the trench is shaped properly and the grade is maintained. Grade is normally maintained by the use of targets or electronic, optical grade control devices (lasers).

Small and gradual variations from grade can be tolerated, providing the line still has adequate capacity after the variations. No reverse grade should be allowed.

Diameter[a] (D)	r (D/2)	X (0.707r)	Y (0.293r)	Z (0.414r)
		inches		
3	1.5	1.060	0.439	0.621
4	2.0	1.414	0.586	0.828
5	2.5	1.768	0.732	1.036
6	3.0	2.121	0.879	1.242
8	4.0	2.828	1.171	1.657

[a] Values are based on typical outside diameters, which are assumed to be 20 percent greater than inside diameters.

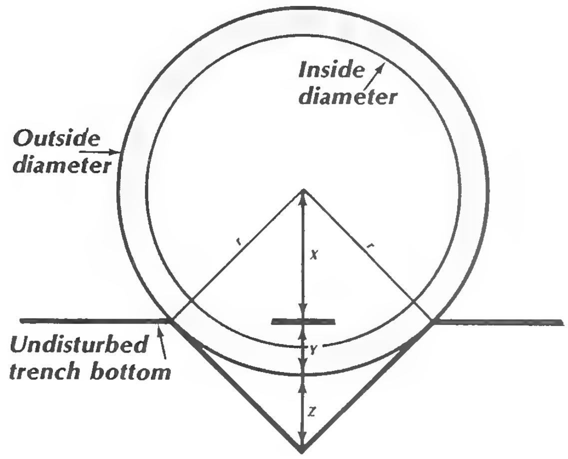


Figure 29. Dimensions for a 90-degree V groove for corrugated plastic tubing.

If the trench is excavated below the designed grade, it should be filled to grade with gravel or well-pulverized soil and tamped enough to provide a firm foundation. The bottom of the trench should then be planed and shaped to grade.

Safety

Observe safety standards for persons and machines. Persons working in trenches should be protected from cave-ins, and they should not work alone. Moving parts of machinery should be protected by proper guards. Persons observing the work should not be permitted to come close to the excavating operation.

Trench method of installation

Constructing the trench

Construction of the trench should begin at the outlet and proceed upgrade. Align trenches in such a way that the drain can be laid in straight lines or in smooth curves. The width of the trench at the top of the drain should be the minimum required to permit installation and enable the bed to support the load on the drain. But there should be at least 3 inches of clearance on either side of the drain.

Tile should be bedded in an earth foundation that is shaped to fit the lower part of the tile. The foundation can be shaped in this way with most trenching machines. If you dig the trench with a backhoe, you will have to hand grade and shape the trench bottom to fit the tile.

For corrugated plastic tubing, a specially shaped groove must be made in the trench bottom if the design does not call for a gravel envelope. The groove provides side and bottom support to the lower part of the tubing and provides a means of controlling alignment during installation. The groove may be in the shape of a semicircle, trapezoid, or a 90-degree V. A 90-degree V groove of sufficient depth is recommended for 3- to 6-inch tubing. However, if the tubing is installed on a steep grade, shape the bottom of the trench to closely fit the tubing.

The groove for tubing can be formed or cut in a number of ways. With all methods, some type of a forming tool is attached to the shoe of the trenching machine. One method is to install a forming tool on the bottom of the shoe and use pressure to form the bedding groove. Another method is either to install a device on the front of the finishing shoe that will plow out the groove during the trenching operation or to attach special shaping cutters to the trenching wheel. The latter methods minimize soil compaction and do not reduce permeability as much as the first method.

Figure 29 shows the dimensions of a 90-degree V groove. The depth at which 3- to 6-inch tubing is set in the groove will vary

according to the size of the tubing. Keep this depth in mind when setting the gradeline. For tubing 8 inches or more in diameter, we recommend a curved bottom that more nearly fits the tubing rather than the 90-degree V groove.

If the drain is to be laid in a rock-cut, the trench should be overexcavated to a depth of 6 inches below grade level; this space should be filled with graded sand and gravel or well-pulverized soil and tamped enough to provide a firm foundation. Then, the bottom of the trench should be shaped and leveled to grade. The trench should be filled with designed bedding or envelope material to the top of the rock-cut.

Where the trench bottom is unstable, as in fine sandy soils or in soils containing quicksand, be extremely careful to keep sediment from entering the drain and to provide a firm foundation for the drain. When draining these types of soils, consider the following suggestions:

- Install the drain only when the soil profile is in the driest possible condition.
- Place stabilizing envelope materials under the drain.
- Cover the remainder of the drain with an envelope material.
- Use nonperforated tubing, self-sealing sewer pipe, or continuous rigid pipe where there are small pockets of noncohesive soils less than 100 feet in length.
- If the drain is tile, be sure that the joints are snug.
- If tubing is used, take precautions to prevent it from floating.

If you find unstable soil at the trench bottom, you can remove and replace it with suitably graded foundation and bedding of processed stone or processed gravel, which will act as an impervious mat into which the unstable soil will not penetrate. The depth of the processed material depends on how unstable the soil is in the trench bottom. Install the foundation and bedding material in layers of no more than 6 inches, and compact. If the foundation contains large particles that create a hazard to the drain, provide a cushion of acceptable bedding material between the foundation and the drain.

Where stabilizer materials do not furnish adequate support, the drain should be placed in a 90-degree, rigid V, prefabricated foundation cradle in which the top of the V equals the outside diameter of the drain. Each section of the cradle must provide rigidity and continuous support throughout the entire length of the cradle. Occasionally, it is necessary to place the cradle on piling; drive pairs of posts along the edge of the cradle into solid material to provide the required support.

If the soil in the trench wall is unstable, the trench sidewalls may cave in and cause tubing failure. This problem may arise where excavation is below groundwater level or in saturated sand. Unstable trench walls may also cause misalignment of tile lines. Where there are unstable trench sidewalls, you should protect the tubing or tile by some means until the drain has been properly laid and blinded. In some cases, the trencher shield behind the shoe can be made longer to protect a greater length of the trench during construction. To install drains in unstable soils, use a fast-moving trencher or trenchless drain plow that can maintain continuous forward motion while disturbing the soil as little as possible.

Installing the drains

Listed below are some guidelines to follow when installing drains:

- Remove all soil or debris inside drains before installation.
- Make sure the drain is free from clinging wet or frozen material that could hinder laying the drain on grade.
- Begin laying tile or tubing at the outlet and progress upgrade. If possible, place the drain inside the shoe casing of the trencher during the trenching operation.
- Automatic drain-laying devices are acceptable, provided that they can lay the drain according to the requirements stated in this publication.
- Lay tubing in the groove and tile on a firm bed that is free of loose soil on the planned grade.
- Hold plastic tubing in position on grade immediately after installation by careful placement of blinding material.
- Where lengths of plastic tubing are to be joined, cut the ends square and remove all ragged or burred edges. Use a plastic coupling to secure the ends of the tubing in proper alignment and to prevent the joint from separating during installation.
- Before work is suspended for the day, blind and backfill all drains laid in trenches.
- Close any open ends tightly with an end plug.
- Use continuous pipe within 100 feet of trees.

Any stretch that occurs during installation of tubing will decrease its strength somewhat and may pull perforations open wider than is desirable. The amount of stretch that occurs during installation depends on the temperature of the tubing at the time it is installed, the amount and duration of drag that occurs when the tub-

ing is fed through the installation equipment, and the stretch resistance of the tubing. Tubing should not be stretched so much that its stiffness is reduced to less than the minimum allowable pipe stiffness. Stretch, which is expressed as a percentage increase of length, should not exceed 5 percent. The use of a power feeder is recommended for all sizes of tubing.

The internal wall temperature of plastic tubing can reach 150° F. or more when it is strung out in a field on a hot, bright day. The ability of corrugated polyethylene tubing to resist deflection is reduced by about 40 percent when its temperature rises from 70° to 100° F. and by about 50 percent when it increases from 70° to 120° F. Therefore, it is essential that the contractor take precautions in hot weather to keep sharp heavy objects from striking the tubing and to prevent excessive pull on the tubing during installation. The tubing will regain its strength when its temperature returns to that of the surrounding soil, which usually occurs five minutes or less after installation.

The stiffness of tubing increases and its flexibility decreases as its temperature is lowered. Rapidly uncoiling tubing in cold weather stresses it excessively and may cause it to crack. The tubing may also have a tendency to coil in cold weather; it is then difficult to lay flat and must be handled with extra care. Ask the manufacturer for recommendations on handling the material in hot or cold weather.

When plastic tubing floats in water during installation, it is difficult to get blinding material around and over the tubing without getting the material underneath it and causing misalignment. You can prevent floating by holding the tubing in place until blinding is completed.

Blinding

Blinding is the placement of bedding material consisting of loose, mellow soil on the sides and over the top of the drain to a depth of 6 inches. The bedding material must permit water to reach the drain easily. Except in areas where chemical deposits in and around the drain area are a problem, the bedding material should be friable top soil or other porous soil. Fine sand should not be placed directly on or around the drain. In soils with low permeability where blinding with soil is not adequate, a suitable envelope should be used. Blinding is not necessary where drains are placed in sand and gravel filters or envelopes.

A number of blinding methods have proven to be acceptable. Some contractors consider blinding so important that they place the material by hand around and over the drain. There are a number of mechanical blinding devices that can be mounted on the trencher. These devices take material from near the top of the trench and place it around and over the drain. Their main advantages are that they blind the drain immediately after laying it, use the most suitable blinding material that is readily available, and reduce labor requirements.

All drains should be blinded immediately to maintain alignment and to protect them from falling rocks, ditch cave-ins, and backfill operations.

Blinding immediately also will help maintain proper alignment of tubing in the groove and protect it when the remaining excavated material is placed in the trench. Careful soil placement on both sides of the tubing is necessary to provide good side support, which will reduce deflection of the tubing. Hold tubing in place in the trench until it is secured by blinding. This step is especially important when water is in the trench and when the air temperature is below 45° F. Under those conditions, you may want to increase the quantity of blinding material.

No stones or other hard objects should be allowed to come into contact with the drain. These objects apply point loads and may cause the drain to fail. Blinding provides protection for the drain during the backfilling operation when the impact of rocks and hard clods could damage it. All lines should be carefully inspected for grade alignment and other specifications before backfilling.

Backfilling

At the conclusion of each day's work, the end of the drain line should be stoppered and the trench backfilled to prevent sediment or debris from entering the line in case of rain. Backfilling should be done even sooner if there is a chance of heavy rain or freezing temperatures. The upper end of each drain should be tightly covered with a manufactured plug or equivalent material.

Various methods can be used to move the remaining excavated material back into the trench and mound it up and over the trench to allow for settlement. These include graders, bulldozers, and auger and conveyer methods. The backfill material should be placed in the trench in such a manner that displacement of the drain will not occur. It is preferable to place the material on an angle so that it flows down the front slope. Avoid large stones, clods, and heavy direct loads during backfill operations. If you are installing tubing on a hot day and the tubing feels warm to the touch (100° F.), delay the backfilling until the tubing reaches the soil temperature.

Trenchless method of installation

In the trenchless plow method, tubing is placed at a prescribed depth in an open channel beneath a temporarily displaced wedge or column of soil. The trenchless plow constructs a smooth-bottomed opening in the soil, maintains the opening until the tubing has been properly installed, and then surrounds it with permeable material.

The plow blade is designed to lift and split the overburden as it moves forward. The lifting action causes a deformation and disruption of the soil upward and outward at an angle on both sides of the plow blade. The slot should be fissured and loosened rather than compacted. The size of the shoe and drain-placing attachment should conform to the outside diameter of the tubing.

Critical depth

The way the trenchless plow moves through the soil influences whether the slot wall is fissured or compacted. A plow 3 to 5 inches wide working at a relatively shallow depth of 3 feet or less in dry soil will disturb the soil as shown in Figure 30a. The soil is broken loose from the base of the plow, heaves forward and upward ahead of the tine, and falls back around the tubing as the plow moves on. This type of disturbance creates cracks and fissures without causing compaction. The same plow working at a much greater depth of 6 to 7 feet in dry soil may tend to move the soil as shown in Figure 30b. Near the surface the soil is disturbed much as it is in drawing A. But below a certain depth, the plow may compress the soil sideways, causing it to become compacted and reducing its permeability. Between these two extremes of working depth there is a certain depth, termed critical depth, where the transition between one type of soil disturbance and the other occurs. This critical depth is the maximum depth at which the trenchless plow can work without causing compaction around the tubing. The critical depth depends upon the forward inclination of the tine, the tine width, the soil moisture content, and the soil density.

In a uniformly compact, dry seedbed, the critical depth will be approximately 15 times the tine width. As the surface layers become very dry and strong or if the soil is of low bulk density and contains large air-filled pores, the critical depth will be reduced to about 10 times the tine width. You can sometimes lower the critical depth by loosening the surface layers of the soil to a depth of 8 to 16 inches in a strip approximately one and one-half times the working depth of the plow. The shallow tining can be done as the plow "returns empty" before the next run. An alternative is to use a double-pass system. The first pass with the plow is made at approximately two-thirds the final depth. Where the critical depth is above the working depth, using a wider tine and loosening the soil surface will reduce the draft force, often by a substantial amount.

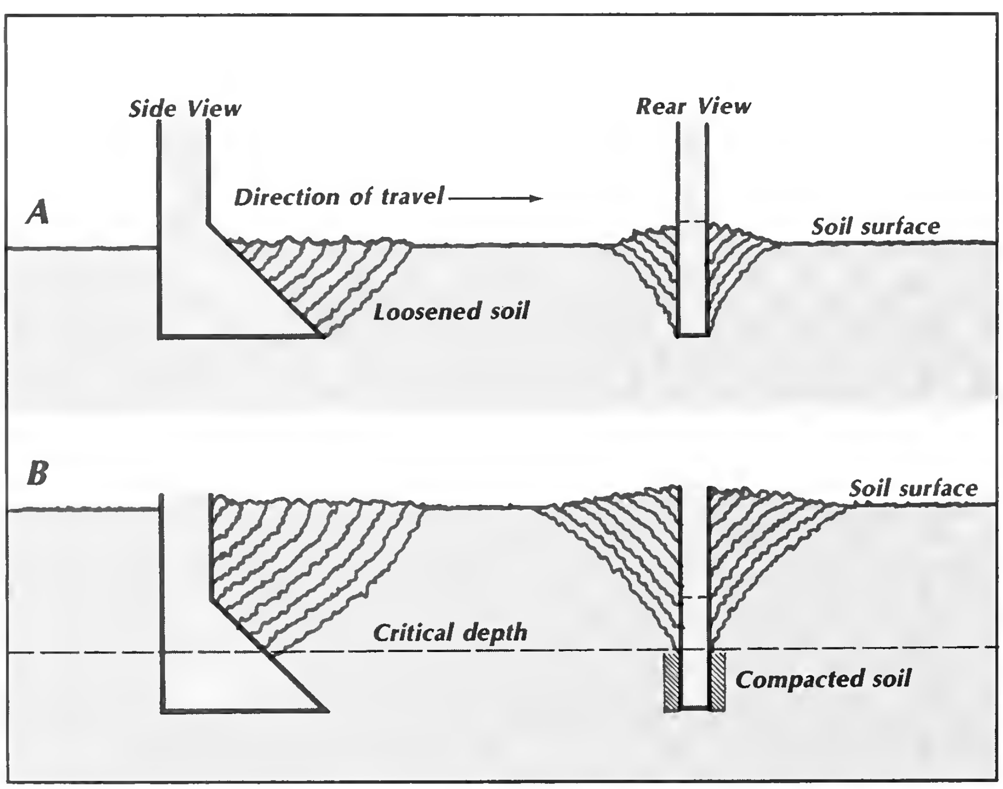


Figure 30. Soil disturbance caused by trenchless plow working at a relatively shallow depth (drawing A) and at a much greater depth (drawing B).

Soil condition

Because soil texture and moisture vary considerably, the soil disruption patterns caused by the trenchless plow will vary. The zone of disturbed soil extends upward and outward at various angles from the vertical, depending on soil conditions, depth, and plow geometry. Soils ranging from sands to clay-loam have properties that permit them to be fractured very readily by the plow. In fact, when the surface layer of these soils is loose, it tends to flow down behind the tubing just as it would during a blinding operation. Wet soil that has high clay content is more likely than other soil types to develop soil structure and compaction problems. Both radial and surface

compaction can occur where tubing is installed in heavy clay soils or wet soil. High-clay soils that are dry, however, can be fractured and fissured to a high degree, facilitating movement of water to the tubing.

Plows do not appear to be affected as much by rocks as are trenchers. In areas where rocks are a problem, the operator should flag any rocks he comes across so that they can later be inspected and removed if necessary. A plow will tend to push smaller rocks aside and move around the larger ones. When large rocks are encountered above or near grade, the plow tends to bounce over them, disrupting the tubing grade. If a rock deflects the plow upward a small distance, an alert operator will, where the slope permits, make a small adjustment in grade from that point on to avoid leaving a hump in the line that would have to be corrected later. If there is an adverse deviation in grade, the point of deviation should be marked. The tubing should be excavated at that point and the grade corrected. The grade should be controlled automatically by means of a laser.

Blinding

To keep the tubing on grade, trenchless plows should be fitted with a device that brings blinding soil over the tubing as it is placed. Where the surface layer is loose, it will flow down freely behind the tubing boot and cover the top of the tubing. This cover is desirable as long as the surface material is highly permeable and stable, but siltation could occur if the surface material is very fine. If a filter is used, a covering of medium to coarse sand around the tubing could enhance inflow.

Stringing tubing

Because trenchless plows operate at high speed, it is sometimes difficult to keep pace when stringing the tubing in the field by hand before installation. To meet the requirements of high-speed plows and to reduce labor and materials costs, spools mounted on trailers have been developed.

Stretch

The amount of stretch depends on the stretch resistance of the tubing, the amount and duration of drag on the tubing as it is fed through the machine, and the temperature of the tubing at the time it is installed. Stretch may also be influenced by your method of handling the tubing when you string it in the field and the way the tubing is picked up and fed into the installation chute. Tubing should not be stretched so much that its stiffness is reduced to less than the minimum allowable pipe stiffness. During installation, stretch should not exceed 5 percent. We recommend that trenchless plows be equipped with a power feeder to reduce stretch.

Maintenance

Although subsurface drainage systems do not require extensive maintenance, the maintenance that is required is extremely important. If the subsurface drains are working, water will stand in the field for only a short time after a heavy rain. If water stands for a few days, the drain may be partly or completely blocked. With drainage systems that have inspection wells or sediment traps, be sure to check the amount and rate of flow at these structures and at the outlets after a heavy rain. A change in flow may indicate that there is a blockage somewhere in the line. Regular inspection of the drainage system is essential. Prompt repair of any drain failure will keep the system in good working order and prevent permanent damage to it.

Outlet ditches

Many subsurface drainage systems fail because the outlet ditches are blocked. If the outlet ditch is filled with sediment, a survey should be conducted to determine how much cleanout work will be required. You should also find out whether some type of conservation practice could be used on the contributing watershed to reduce soil movement.

Surface inlets

Poorly constructed surface inlets are subject to severe damage and require frequent repair. Because inlet covers often become sealed with trash, they should be checked frequently. Clean the covers after a heavy rain and replace them carefully. If a cover is removed, trash can enter and block the line.

Blowouts

Repair holes over subsurface drains at once. Otherwise, large amounts of soil may wash into the lines and block the entire system. Holes form where a drain is broken or where joints or slots are too wide. If the tile is broken, replace it. If the joint is too wide, place tile bats (pieces of broken tile) over the joint to prevent soil from washing into the line. To repair crushed or punctured corrugated plastic tubing, cut the damaged segment from the line and replace it with new tubing, using the manufacturer's couplers.

Sediment

Sediment traps can be used for subsurface drains that are laid in fine sand or silty soils. If the traps are cleaned periodically, they will keep soil from filling the lines. Clean the traps every few days just after the lines are laid be-

cause at first sizeable quantities of fine soil will wash in through the joints between tiles or through perforations in plastic tubing. After one freezing and thawing cycle, soil will wash in more slowly, and you will need to check the traps only once or twice a year. You can gain access to drainage lines and flush them through inspection wells.

Tree roots

Willow, elm, soft maple, cottonwood, and other water-loving trees that grow within approximately 100 feet of the drain should be removed. Maintain a clearance of 50 feet between the drain and other species of trees.

Ochre accumulations

Ochre, which is an iron oxide, may block the drain when iron in solution moves from the soil to the drain and accumulates there. The process by which ochre accumulates may be chemical, microbial, or both. Ochre usually enters drains through organic soils but has been known to occur in other soils as well. There is no foolproof solution (except construction of open ditches) to the ochre problem. Jetting the drain with an acid solution has proven successful in some areas, but that remedy is very costly.

Pumping plants

Where it is impossible or uneconomical to install outlets for drainage, drainage pumping plants can be used to remove excess surface water or groundwater. Pumping plants are also used where outlets are adequate except during prolonged periods of high water. If you are considering installing a pumping plant, be sure that its use is within the limitations of Illinois drainage law.

In solving drainage problems that involve pumping, take into account the capacity of the drainage system outlet, the capacity of the pump, its location and type, and the size of the sump. Determine the cost of all practical solutions. To be economically feasible, a pumping plant must be designed in such a way that annual operation costs are low. A pump that costs relatively little to install but that has a high annual cost of operation may not be the most economical.

A preliminary survey will determine the condition of the drainage outlet and help you decide whether pumping is required. A drainage system with a pumping plant that is designed into the system will usually function much more efficiently than one to which the pump is added later when the outlet is found to be inadequate.

The pumping plant must be designed to pump enough water to provide adequate drainage against the total head expected. (Total head considers all possible sources of resistance, from elevation to friction to couplings and joints.) Because pumping plants that are designed to pump surface runoff are complex and expensive, as much surface runoff as possible should be diverted from the site of the plant.

Selecting a site

The pumping plant should be located where it can best serve its purpose. In choosing a location, consider the stability of the foundation material, accessibility for servicing, proximity to sources of power, and susceptibility to vandalism. In areas where ample sump storage is available, the pumping plant should be located so as to take maximum advantage of the storage. Select a location that will permit safe discharge into the outlet with a minimum of construction outside the diked area. If possible, locate the plant in a place that is readily accessible in all types of weather.

The requirement of a stable foundation is an important aspect in selecting a location. Before deciding upon a site, make borings to ensure that the location has the best foundation and that it meets as many of the other site requirements as possible.

Selecting pumps

In selecting a pump, consider the type, characteristics, capacity, total head, the kind and source of power, shape and size of pump, housing, and method of operation. Pumps used for pump drainage are in the high-volume, low-head class. This class includes axial-flow propeller pumps and certain centrifugal pumps. For pumping from small capacity tile, you can use commercial sump pumps. Determine pumping volumes and heads carefully since friction factors become critical at settings other than those recommended by the manufacturer.

Electric power permits automatic operation and eliminates the need for daily fueling or servicing. Usually, a 10-horsepower motor is the largest that can be used on single-phase, 230-volt lines. Larger motors can be operated on three-phase power, which is available in some areas, or where phase converters can be used on single-phase power lines. If you plan to use electric power for pump drainage installations, consult the power supplier for suggestions and recommendations as to the best arrangement. If electric power is not available, you can operate the pump with diesel, gasoline, or LP gas stationary power units. Belt or power takeoff drives can be used to couple farm tractors to the pump. The size of the pump depends upon the total head and the quantity of water pumped. The rated size is usually designated by the diameter of the pipe column at the discharge end of the pump. The design column veloc-

ity in the discharge pipe may range from 7 to 12 feet per second, with the highest efficiency usually occurring at values of 8 to 10 feet per second.

Pump capacity

The required capacity of pumping plants can be determined from drainage coefficients applied to the area served, empirical formulas, a study of existing installations, or direct analysis using hydrologic procedures. The capacity of pumping plants for drainage areas of up to 1 square mile can be determined from applicable drainage coefficients (Table 5) or computed through hydrologic procedures. Hydrologic procedures should always be used whenever the drainage area exceeds 1 square mile. If you determine pump capacity from the drainage coefficient, use the following equation:

$$Q = 18.9 \times C \times A$$

where

Q = pump capacity, gallons per minute (GPM),

C = drainage coefficient (inches per 24 hours),

A = area of the watershed (acres).

Regardless of the method you use, be sure that the pump capacity is no less than the minimum values suggested below. Where only subsurface drainage water is pumped, the capacity of the pump should be no less than the maximum capacity of the drainage system plus 20 percent. When both subsurface and surface water are to be pumped for field crops, the pump should have the capacity to remove 1 inch of water from the contributing drainage area in 24 hours. When special or high-value crops are to be grown, the pump should be able to remove 1½ to 4 inches of water in 24 hours, depending upon how much runoff water can be stored in the ditches and watershed and upon the degree of protection desired. Where seepage is a problem, select a pump with additional capacity.

Power requirements

The power required to achieve the designed pumping rate depends upon the head against which the water must be pumped and the efficiency of the plant. The horsepower required to move a given quantity of water against a specific head can be calculated with this formula:

$$HP = \frac{Q \times H}{3{,}960 \times e}$$

where

HP = horsepower required to move the water,

Q = pump capacity (GPM),

H = total head (feet), which includes the difference in elevation between inlet water level and discharge water level as well as friction losses in the pump and fittings

e = efficiency of the unit (equal to the pump efficiency times the drive efficiency; pump efficiency varies from 50 to 75 percent and drive efficiency from 90 to 100 percent).

The horsepower you determine with this formula will be the continuous-duty requirement. For electric motors, this figure will be the nameplate rating. For internal combustion engines, the minimum engine size will be the calculated horsepower plus the power required to operate accessories.

Before installing the pumping system, estimate the daily cost of pumping to complete a cost-benefit ratio. If the source of power is an electric motor, you can use this information in making the computations:

1 horsepower/day = 17.9 kilowatt hrs/day

Water storage

To prevent the motor from starting too frequently, you must provide space for temporary storage of water. In small areas an enclosed sump or pump bay may be enough storage. Enclosed sumps can be constructed from silo staves, manhole blocks, or a series of large sewer or metal pipe sections. For large subsurface drainage systems where subsurface water must be pumped, an open ditch or large pit is usually the best type of storage.

For automatic operation, provide enough water storage so that the maximum number of operation cycles will be limited to 10 per hour. Estimate the required storage using these formulas:

$$\text{active storage (cubic feet)} = \frac{Q \times 2}{N}$$

$$\text{storage area in sump (square feet)} = \frac{Q \times 2}{N \times d}$$

where

Q = pump capacity (GPM)

d = the depth (in feet) of storage or distance between water levels that will start and stop pump operations,

N = cycles per hour.

The amount of active water storage must be greater for manually operated pumps than for automatic ones. The amount also depends upon the number of times the operator is willing to start the pump. Where the number of starts is limited to two a day, estimate the active storage desirable using these formulas:

$$\text{active storage (cubic feet)} = Q \times 25$$

$$\text{storage area in sump (square feet)} = \frac{Q \times 25}{d}$$

The depth of storage (or distance between the water level at which the pump starts and at which it stops) should be about 2 feet for sumps and 1 foot for ditches. This depth reduces changes in the operating characteristics of the pump caused by changes in water level. Sumps should have a paved base and weep holes in the walls. The base provides a solid foundation for the sump wall and supports the weight of the pump and sump cover. Weep holes prevent flotation of the sump.

Pump bay

The sump or bay should be designed after the pump has been selected. Be sure to provide proper clearance and submergence in the pump bay for the pump you select (most manufacturers make recommendations for these dimensions), and protect the pump and motor from flooding at all times. See Figure 31.

Operation and cycling

Although pumping is cyclic in design, the electric motor used to power a pump should have a continuous load rating to take care of sustained water inflow. Electric motors can easily be controlled by float switches. An internal combustion engine will have to be controlled manually for certain periods, or it can be made automatic by some kind of throttle or clutch control. Automatic safety cutouts will eliminate the need for an operator during most of the time the engine is running. Safety cutouts (based on engine temperature, engine oil pressure, or pump pressure) should be attached to any engine that is to be left running unattended for any length of time.

Trash racks

Provide trash racks or protective screening to prevent floating debris from entering the sump and damaging the pump. The velocity of flow through the rack should not exceed 2 feet per second. Recommended spacing for trash rack bars is ¾ inch for a pump 16 inches in diameter, 1 to 1½ inches for diameters 18 to 24 inches, and 2 inches for ones 30 to 42 inches.

The trash rack should be shaped so that it can easily be cleaned by hand, or it should be equipped with mechanical cleaners. If the pump is too small for trash racks, use galvanized basket strainers to prevent small gravel and debris from entering the sump. For more details on the design of pumping plants, refer to Chapter 7, "Drainage of Agricultural Land," in Section 16 of the Soil Conservation Service *National Engineering Handbook.*

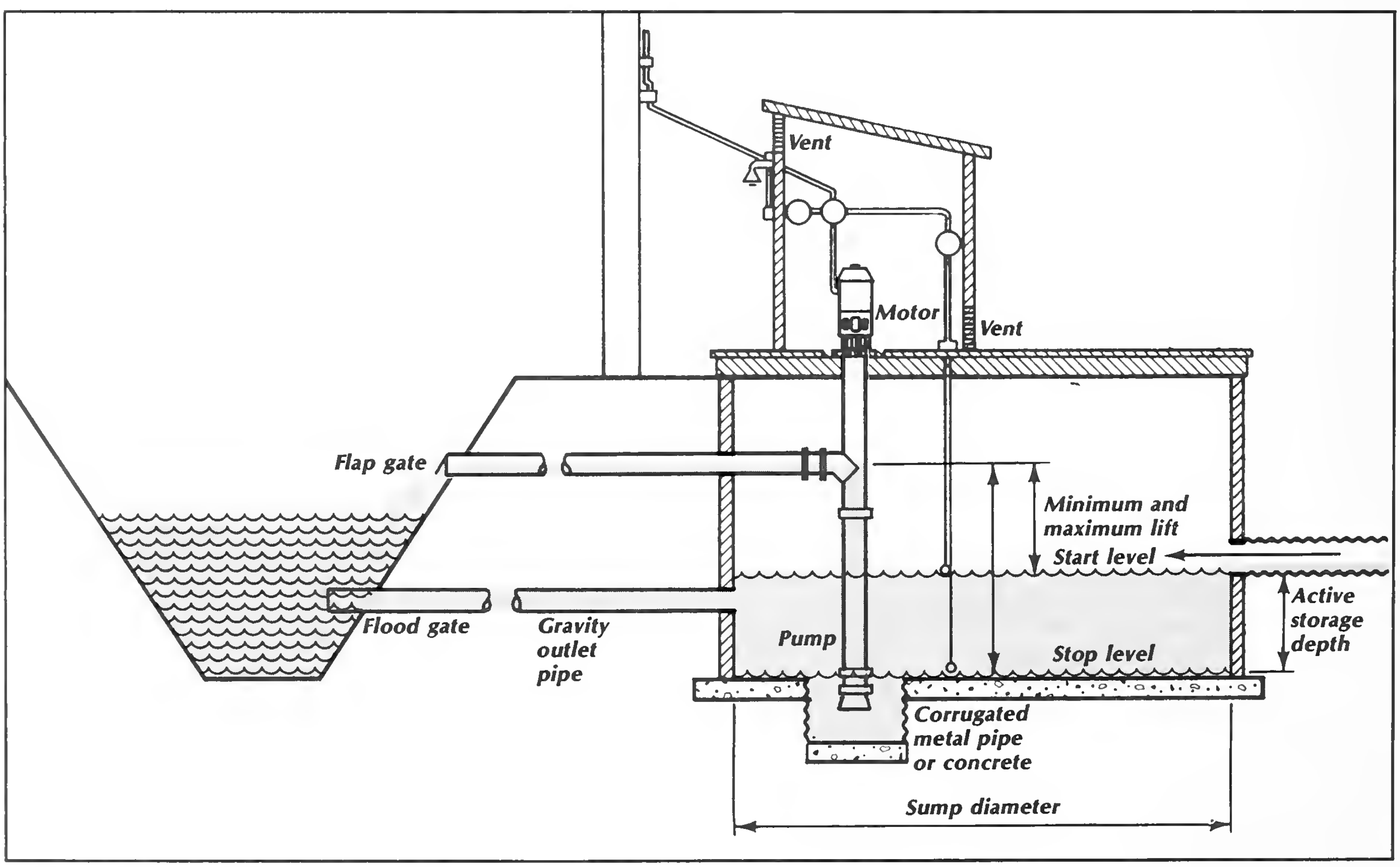


Figure 31. Design of drainage pumping plant.

Basic Terminolog

Backfilling	Placement of excavated soil in the trench after blinding has been completed.
Bedding	The earth foundation of the trench together with the select material around and over the drain, including envelope and filter material where used.
Berm	Strip or area of land, usually level, between the spoil bank and the edge of a channel or ditch.
Blinding	Placement of select soil around a drain to prevent damage or misalignment when the trench is backfilled and to allow water to flow freely to the drain.
Coefficient of roughness	Factor expressing the frictional resistance to flow of a channel surface or a drain interior.
Connections	Fittings used to join two drain lines.
Continuous pipe	Extended length of pipe without perforations or unsealed joints.
Deflection	Decrease in vertical diameter of tubing, often influenced by loading.
Ditch	Constructed open channel for conducting water. See Drain.
Diversion	Channel constructed across the slope for the purpose of intercepting surface runoff.
Drain	Conduit below the ground surface for removal of surplus ground or surface water. See Ditch.
Drainage area	Area from which drainage water is collected and delivered to an outlet. Sometimes referred to as the watershed area for a particular drain.
Drainage coefficient	The depth of water, in inches, to be removed from an area within 24 hours.
Drainage system	Collection of surface ditches or subsurface drains, together with structures and pumps used to collect and dispose of excess surface or subsurface water.
Field ditch	A graded ditch generally crossable with field equipment for collecting excess water from a field.
Grade or gradeline	Degree of slope of a channel or natural ground.
Inspection well	Opening to surface in drain line to permit observation of flow conditions.
Interceptor line or drain	Surface ditch or subsurface drain, or a combination of both, designed and installed to intercept flowing water. Also, a line used to intercept several lines to keep the number of crossings at highways and similar locations to a minimum (also called collector lines).
Junction	Point of intersection of two or more surface ditches or subsurface drains.
Lateral ditch	Principal channel or ditch that conducts drainage water from the field ditches to an outlet channel.
Lateral drain	Secondary drain that collects excess water from a field.
Main drain	Principal drain that conducts drainage water from the lateral drains and submains to an outlet.
Outlet channel	Channel constructed primarily to carry water from manmade structures such as drain lines, surface ditches, diversions, and terraces.
Pipe	A continuous length of nonperforated conduit typically used to protect an outlet or to provide additional structural strength.
Pipe drop inlet	Type of surface water inlet, fabricated from pipe materials, which lowers surface water to a ditch bottom.
Pumping plant	One or more pumps, power units, and appurtenances for lifting drainage water from a collecting basin to a gravity outlet.

Slope Degree of deviation of a surface from the horizontal, usually expressed in percent or a ratio of horizontal to vertical (i.e., 4:1).

Slot Perforations in plastic tubing. Also, the opening in the ground created by the trenchless plow as it lays the tubing.

Spoil bank Soil excavated from channel, ditch, or other site and placed along the excavation site.

Stretch The increase in length of the tubing caused by tension forces during installation. It is expressed as a percent increase of the length prior to installation.

Submain Branch drain off the main drain which collects discharge water from laterals or from the field.

Tile Drains made of burned clay, concrete, or similar material, in short lengths, usually laid with open joints to collect and carry excess water from the soil.

Tubing A flexible drain that gains part of its vertical soil load-carrying capacity by lateral support from the surrounding soil.

Watershed Total land area above a given point on a stream or waterway that contributes runoff to that point.

Useful Conversion Factors

To convert	Into	Multiply by
Acres	hectares	0.405
Acres	square feet	43,560
Acres	square meters	4,047
Acres	square yards	4,840
centimeters	feet	0.0328
centimeters	inches	0.394
centimeters	meters	0.01
centimeters	yards	0.0109
cubic feet	cubic inches	1,728
cubic feet	cubic meters	0.0283
cubic feet	gallons	7.48
cubic feet	liters	28.3
cubic inches	cubic feet	0.00058
cubic inches	gallons	0.0043
cubic inches	liters	0.0164
cubic meters	cubic feet	35.3
cubic meters	cubic inches	61,023
cubic meters	gallons	264.2
cubic meters	liters	1,000
feet	centimeters	30.48
feet	inches	12
feet	meters	0.305
feet	yards	0.333
gallons	cubic feet	0.134
gallons	cubic inches	231
gallons	cubic meters	0.0038
gallons	liters	3.79
hectares	Acres	2.47
hectares	square feet	107,600
hectares	square meters	10,000
hectares	square yards	11,956
inches	centimeters	2.54
inches	feet	0.083
inches	yards	0.0278
kilometers	feet	3,281
kilometers	meters	1,000
kilometers	miles	0.62
kilometers	yards	1,094

To convert	Into	Multiply by
liters	cubic feet	0.0353
liters	cubic inches	61.02
liters	cubic meters	0.001
liters	gallons	0.264
meters	centimeters	100
meters	feet	3.281
meters	inches	39.37
meters	kilometers	0.001
meters	yards	1.094
miles	feet	5,280
miles	kilometers	1.61
miles	meters	1,609
miles	yards	1,760
square centimeters	square inches	0.155
square centimeters	square meters	0.0001
square feet	square inches	144
square feet	square meters	0.0929
square feet	square yards	0.1111
square inches	square centimeters	6.45
square inches	square feet	0.007
square inches	square meters	0.00064
square meters	hectares	0.0001
square meters	square centimeters	10,000
square meters	square feet	10.76
square meters	square inches	1,550
square meters	square yards	1.2
square yards	square feet	9
square yards	square inches	1,296
square yards	square meters	0.8361
yards	centimeters	91.44
yards	feet	3
yards	inches	36
yards	meters	0.914